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A journal of plant ecology for eastern Australia

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Cunninghamia

A journal of plant ecology for eastern Australia

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Allan Cunningham, botanist and explorer (1791–1839)

Cover: Mature Yellow Box (*Eucalyptus melliodora*) grassy woodland, Mount Ainslie, Canberra, one of the threatened communities within the South-east Highlands Bioregion

Photo: Nicholas Gellie

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Native Vegetation of the Southern Forests: South-east Highlands, Australian Alps, South-west Slopes, and SE Corner bioregions

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Abstract: The Southern Forests study area covers an area of about six million hectares of south-eastern New South Wales, south of Oberon and Kiama and east of Albury and Boorowa (latitude 33° 02′–37 ° 06′ S; longitude 146° 56′ – 147° 06′ E). The total area of existing vegetation mapped was three million hectares (3 120 400 hectares) or about 50% of the study area. Terrestrial, wetland and estuarine vegetation of the Southern Forests region were classified into 206 vegetation groups and mapped at a scale between 1: 25 000 and 1: 100 000. The classification was based on a cluster analysis of detailed field surveys of vascular plants, as well as field knowledge in the absence of field survey data. The primary classification was based on 3740 vegetation samples with full floristics cover abundance data. Additional classifications of full floristics presence-absence and tree canopy data were carried out to guide mapping in areas with few full floristic samples. The mapping of extant vegetation was carried out by tagging vegetation polygons with vegetation codes, guided by expert knowledge, using field survey data classified into vegetation groups, remote sensing, and other environmental spatial data. The mapping of pre-1750 vegetation involved tagging of soils mapping with vegetation codes at 1: 100 000 scale, guided by spatial modelling of vegetation groups using generalised additive statistical models (GAMS), and expert knowledge. Profiles of each of the vegetation groups on the CD-ROM* provide key indicator species, descriptions, statistics and lists of informative plant species.

The 206 vegetation groups cover the full range of natural vegetation, including rainforests, moist eucalypt forests, dry shrub forests, grassy forests, mallee low forests, heathlands, shrublands, grasslands and wetlands. There are 138 groups of *Eucalyptus* forests or woodlands, 12 rainforest groups, and 46 non-forest groups. Of the 206 groups, 193 were classified and mapped in the study area. Thirteen vegetation groups were not mapped because of their small size and lack of samples, or because they fell outside the study area.

Updated regional extant and pre-1750 vegetation maps of southern New South Wales have been produced in 2005, based on those originally prepared in 2000 for the southern Regional Forest Agreement (RFA). Further validation and remapping of extant vegetation over 10% of the study area has subsequently improved the quality of the vegetation map, and removed some of the errors in the original version. The revised map provides a reasonable representation of native vegetation at a scale between 1: 25 000 and 1: 100 000 across the study area.

In 2005 native vegetation covers 50% of the study area. Environmental pressures on the remaining vegetation include clearing, habitat degradation from weeds and nutrification, severe droughts, changing fire regimes, and urbanisation. Grassy woodlands and forests, temperate grasslands, and coastal and riparian vegetation have been the most reduced in areal extent. Over 90% of the grassy woodlands and temperate grasslands have been lost. Conservation of the remaining vegetation in these formations is problematic because of the small, discontinuous, and degraded nature of the remaining patches of vegetation.

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Introduction

The Comprehensive Regional Assessments (CRAs) were designed to provide scientific information to create a Comprehensive, Adequate, and Representative (CAR) conservation reserve system on public lands, and at the same time set up systems of Ecologically Sustainable Forest Management (ESFM) within designated forest regions in New South Wales, Victoria, Queensland, Tasmania and Western Australia. One of the key pieces of scientific information needed was a map of forests and non-forests within the forest regions. The JANIS report (JANIS 1996) placed considerable emphasis on using 'forest ecosystems' as general surrogates for the range of biodiversity. The JANIS report defines a forest ecosystem as:

The aggregate of plants, animals and other organisms, and the non-living parts of the environment with which these organisms interact.

……an indigenous ecosystem with an overstorey of trees that have a greater than 20% canopy cover. These ecosystems

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*CD-ROM is inside back cover

should normally be discriminated at a resolution requiring a map-standard scale of 1: 100 000. Preferably these units should be defined in terms of floristic composition in combination with substrate and position within the landscape.'

The conservation representativeness of forest ecosystems in a given region was a key factor in the conservation assessment of a forest region, along with other criteria including flora and fauna species, wilderness, cultural values and old growth. Keith & Bedward (1999) have detailed a comprehensive summary of the validity of forest ecosystems as surrogates for biodiversity. Section 6.1.1 of the JANIS report also specifies additional requirements relating to the derivation and use of forest ecosystems in the CRA/RFA process:

These broad specifications provided the framework for developing a regional scale vegetation map for the Southern Forests of New South Wales. The approach adopted was designed to be consistent with the vegetation classification in the Eden CRA Region (Keith & Bedward 1999); to incorporate the range of field survey and mapping data already available; and to use an overstorey mapping layer to help delineate the extent of each forest and non-forest ecosystem. In this paper forest and non-forest ecosystems are synonymous with the more generic term vegetation groups.

This study presents up-to-date versions of the extant and pre-1750 vegetation maps of the Southern Forests, based on a thorough revision of the original CRA work completed in 2000. The specific objectives of this study are to document the data and methods used to produce these maps, to illustrate the more recent changes and revisions, to describe a newly developed hierarchical vegetation classification scheme and to indicate the current status of vegetation groups across the study area.

The Southern Forests study area

The Southern Forests study area covers six million hectares (6 174 400 hectares) of south-eastern New South Wales (latitude 33° 02′–37° 06′ S; longitude 146° 56′–147° 06′ E) (Fig. 1). The northern boundary extends from the Crookwell and Oberon Plateaus, across to the southern part of the Illawarra near Kiama. The eastern boundary follows the South Coast down to the boundary of the Eden Forests region. The south eastern boundary excludes the South-East Forests region and then follows the NSW state border to Albury. The western boundary more or less follows the Hume Highway to Bookham and then heads due north to the Abercrombie River. The study area includes hardwood forest regions, based on NSW State Forest's administration regions at the time of the CRA, and areas covered by the CRA wilderness assessment including:

- the Jamberoo escarpment, up to the Southern Highlands highway between Moss Vale and Kiama;
- small areas of southern Blue Mountains National Park, for wilderness assessment;
- hardwood forests of Jenolan State Forest adjoining Kanangra-Boyd NP;
- Pulletop and Livingstone State Forests, south of Wagga.

Landscapes

The landscapes of the study area fall within five IBRA bioregions (Thackway & Creswell 1995): Australian Alps, South Eastern Highlands, South-East Corner, Sydney Basin, and the NSW South-Western Slopes (Fig. 1).

The elevated plateau of the Australian Alps bioregion extends from the Victorian border to the Australian Capital Territory. The highest point is Mount Kosciuszko, 2228m above sea level. Altitude decreases to 1350 metres in the northern part of the Alps, within the Australian Capital Territory. The Australian Alps were formed primarily from large intrusive granite batholiths, interspersed with metamorphic schists, gneists, and acid volcanics.

The Murray River drains the high western escarpments of the Australian Alps. Landscapes on the western footslopes have formed on granite and granodiorites, and Ordovician metasediments, including siltstones, mudstones and shales. Quaternary riverine alluvium fills the valleys of the larger streams and rivers.

On the south-eastern side of the Australian Alps, the Snowy River dissects the dry rainshadow areas of the Byadbo and Delegate catchments of mainly Silurian siltstones and shales. This dry landscape forms part of the South-East Corner bioregion and shares affinities with the drier rainshadow areas of the south coast.

The Murrumbidgee River and its tributaries drain the central eastern and northern sides of the Kosciuszko and Brindabella Ranges. On the eastern side of these mountain ranges, the landscape is mainly undulating high plateaus 600 to 900 m in elevation with intervening high ranges up to 1400 m, such as the Yaouk, Cooma, Tinderry, Numeralla, and Gourock Ranges. The geology of the Numeralla and Gourock ranges consists of a complex series of Cambrian-Ordovician schists. The Yaouk and Cooma Ranges consist of Ordovician and Silurian sediments and shales, interbedded with acid volcanics in the ranges further to the East. The Cooma-Monaro plains comprise Tertiary basalt. Further to the south and east of these plains, Ordovician and Silurian sandstones are interbedded with Silurian and Devonian granites and Ordovician metasediments. Cainozoic alluvial plains can be found on the broad plains to the west of Goulburn in the upper parts of the Lachlan River catchment. The landscapes that have formed on these geologies fall largely within the South Eastern Highlands bioregion.

The abrupt fall on the eastern escarpment coincides with the catchments of the eastern flowing river systems dissecting the broad Morton plateau in the north and the Deua and Wadbilliga ranges in the central and southern parts of the South Coast escarpment. These ranges comprise Ordovician

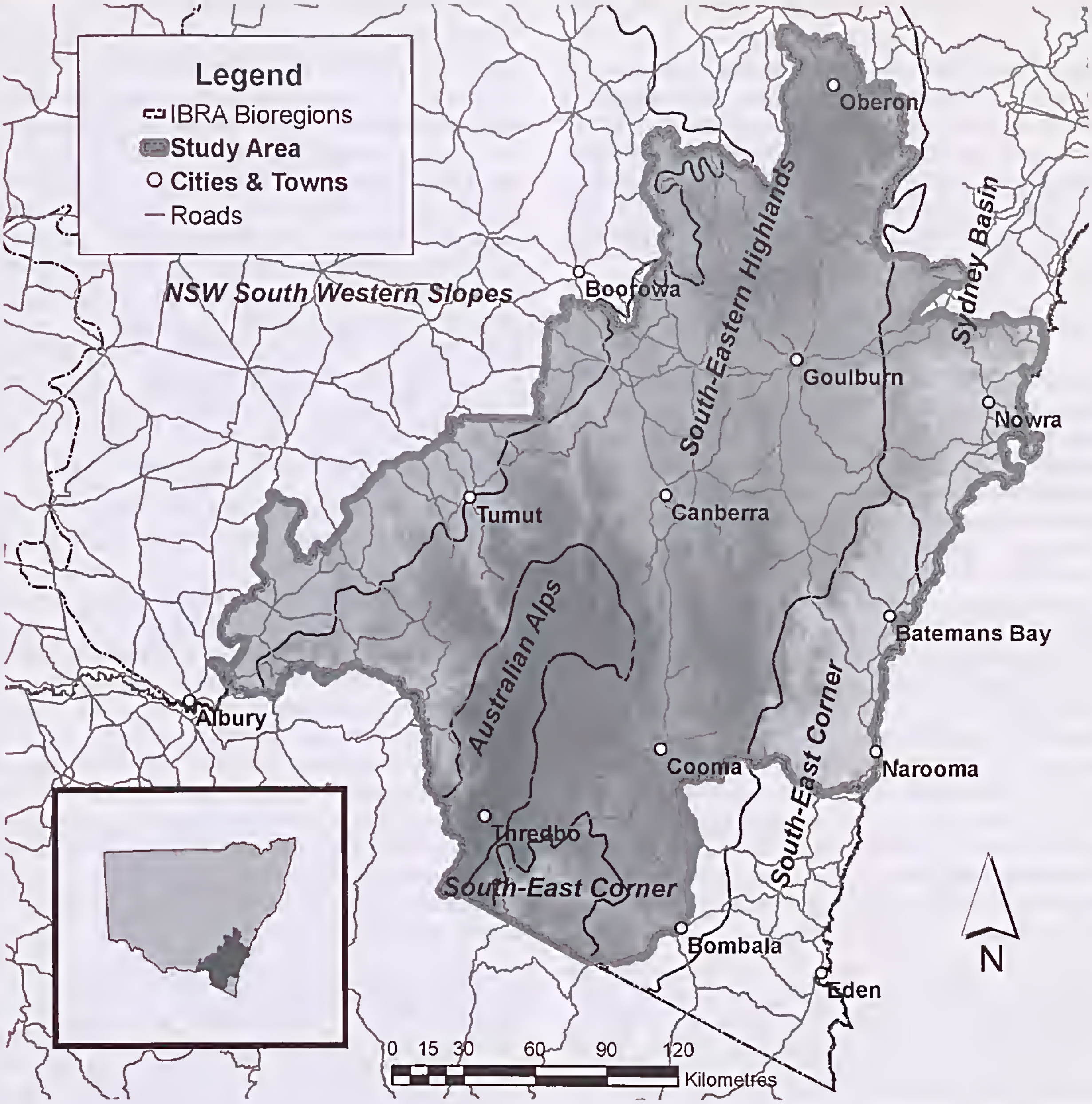

Fig 1. The Southern Forests study area showing bioregions

conglomerates, sandstone, siltstone, and shale, overlying a thin belt of Comerong acid volcanics, which produce some of the rugged high outcrops in the Deua ranges. The foothills of the South Coast are undulating low hills made up of Ordovician shales, conglomerates, and siltstones, interspersed with scattered basalt outcrops at Mount Dromedary, south-west of Narooma, and at Mount Durras, north of Batemans Bay. These landscape types extend from the South-East Forests region in Eden up to the edge of the Morton and Budawang ranges in the lower and middle parts of the Clyde valley to underlie the coastal foothills extending southwards through Yadboro and Dampier State Forests. Alluvial landscapes are found in the lower Shoalhaven, Deua and Tuross River catchments. The coastal area between Bermagui and the Illawarra has numerous estuarine lake systems. Granite batholiths intrude along the coast and are found west of Nelligen, around Moruya and Bodalla, and in the central section of the Tuross catchment. These landscapes extending up from Victoria through Eden and Bega form the northern part of the South-East Corner bioregion.

Permian siltstones, shales, and sandstones dominate the geology of the Morton and Budderoo plateaus on the northern part of the South Coast escarpment and extend in a wedge down to Mount Durras, north of Batemans Bay. These are part of the Sydney Basin bioregion. The north-eastern boundary of the study area straddles the Illawarra escarpment, a high rainfall part of the Sydney Basin bioregion.

The northern part of the study area comprises undulating high plateaus of granite and basalt, surrounded by Devonian and Ordovician sandstone, quartz sandstone, siltstones and shales. These plateaus include Oberon, Kanangra-Boyd, and Crookwell-Taralga, and, with elevations from 900 to 1300 m, define the Great Divide. To the east of the northern high plateaus, highly dissected hills 300 to 400 m in elevation, rapidly descend to the Kowmung and Wollondilly Rivers. In the dissected valleys, Devonian quartzites, sandstones, and shales predominate.

Climate

Mean annual rainfall ranges from 465 mm at Cooma on the Monaro plains to over 2300 mm at Charlottes Pass in the Snowy Mountains. Rainfall is lowest on the Monaro plains, increasing east towards the coast and west to the mountains. Deep valleys or lower plateaus on the leeward side of higher mountain ranges result in areas of lower rainfall, examples of which are found in the rain-shadow valleys of the Araluen Valley, the Monaro plains and the middle Snowy and Murrumbidgee catchments. By contrast, average annual rainfall above 1200 mm is found on the Kanangra-Boyd plateau, and along the South Coast escarpment extending from Kiama down to the Wadbilliga ranges.

During winter snowfalls are common above 1000 m on the Australian Alps and the Central and Southern Tablelands. Snow covers the higher parts of the Australian Alps, above 1600 m, for periods up to four months. Heavy frosts are a frequent occurrence over most of the South-East Highlands and Australian Alps during the winter months, becoming more severe in broader deep valleys fringing the mountain ranges, as a result of cold air drainage.

Mean annual temperature ranges from 2° C near Mount Kosciuszko, to 16° C along the coastal plains north of Ulladulla. Temperature increases as the elevation falls in both easterly and westerly directions away from the higher mountain ranges and the Great Dividing Range, which splits the region in half from north to south (NPWS 1998). These extremes greatly influence the distribution and pattern of vegetation. Seasonality of rainfall also varies across the study area. The northern coastal escarpment around Kiama shows a strong summer peak in rainfall, while the western side of the Kosciusko ranges shows a strong winter rainfall peak.

Land Use History

European land use across the study area has been mainly forestry, agriculture, mining and human settlement. On the Central Tablelands and Western Slopes, large areas were opened up to pastoral development from the 1830s onwards. Much of this land was covered in grassy woodlands. The steeper, more infertile and more remote forested land on the Tablelands was either occasionally cleared or left for rough grazing and selective logging. Evidence of these activities is still present in the forest structure on private or public land today.

Mills and Jakeman (1995) provide a detailed account of the land use changes in the Illawarra and adjacent Southern Highlands. They document the remorseless cutting and clearing of the Kiama and Shoalhaven coastal foothills, as well as the forests on basalt. Harvesting of *Toona australis* (Red Cedar) commenced in 1810, following the first allocation of land grants to settlers. By 1850 the settlers had cut out most of the cedar trees. Expansion of farming caused the clearance of coastal rainforests and forests in the southern Illawarra, Gerringong, and lower Shoalhaven causing major losses to the Illawarra Brush. Clearing of sub-tropical rainforest on the coastal lowland rainforests began after the 1860s. The Yarrawa Brush and the tall moist forests on basalt near Robertson were cleared for agriculture. Kangaroo Valley was not settled till the 1870s because of poor access, but the open grassy forests in the valley were gradually cleared for farming thereafter.

From about 1880 until 1950, significant areas of Crown Land in the central and northern parts of the study area were made available for free selection and selective timber cutting. State forests were established during this period to protect the forest resource, in response to excessive forest clearing for agriculture, grazing, and mining. Bago, Buccleuch and Meragle State Forests in the western highlands had a long history of forest harvesting since the late 1800s. These sub-alpine forests were also grazed from time to time under occupational grazing permits. From 1900 to the early 1950s state forests were the principal means of conserving forests, although more intensive harvesting became more widespread as bullock teams, axe, and crosscut saws were replaced with mechanised machinery, chainsaws, and a more extensive road network to gain access to more of the timber resource after the Second World War.

A succession of major wildfires burnt through the Snowy Mountains and Brindabella Ranges in 1926, and again in 1939, causing significant soil loss, and changes in the forest structure (Costin 1954). These fires, coupled with the intense grazing of the alpine areas, brought about the need to protect water catchments for hydro-electricity and water conservation schemes. In 1944 Kosciuszko State Park was gazetted over the alpine and sub-alpine areas of the Snowy Mountains plateau.

With the formation of the National Parks and Wildlife Service in 1967, further Crown Land was dedicated as National Park including Kanangra-Boyd and southern Blue Mountains National Parks in 1975, and Morton National Park in 1976. Although run by a conservation trust from the 1930s, Deua and Budawang National Parks were formally gazetted in 1977, and Abercrombie and Brindabella National Parks in 1996.

Extensive pine plantations were established on State Forests on the eastern slopes of the Tumbarumba and Tumut districts, on the Oberon Plateau and in Tallaganda State Forest during the 1960s and 1970s. These pine plantations were established on areas cleared of native *Eucalyptus* forest. Clearing of native forest for pine plantation ceased in the late 1970s as public concern grew about the impact of large scale conversion of publicly owned native forest to pine plantation.

During the 1960s, private plantation schemes tried to convert significant areas of forest into pine plantation. These schemes concentrated on clearing of woodlands and heathland in the Oalen Ford-Braidwood area. Because the schemes overlooked the infertility and shallowness of the soils, patches of failed pine plantation remain amongst partially disturbed areas of native forest in this area. Pine plantations since then have been established on privately owned pastoral land.

On the South Coast the more rugged and steep areas remained in public tenure, mainly as State Forest and Crown Land. Since the 1880s the more fertile flats and valleys have been cleared for small dairy farms and residential development close to towns. Since the 1970s, much of the Crown Land along the South Coast escarpment has been progressively dedicated as national park. National parks were established to protect the coastline environment during the 1980s and 1990s and since 1990 tourism has become a major contributor to regional economics of the South Coast, ACT, and the Snowy Mountains. The introduction of intensive tourism or nature-based tourism poses new challenges for nature conservation.

Methods

Auditing Vegetation Samples

A thorough compilation of field survey data was made from major surveys carried out by CSIRO (Gunn et al. 1969, Austin 1978, Austin and Cawsey 1996, Austin et al. 1996, Doherty 1996, 1997, 1998a, 1998b), State Forests (Binns 1997a and 1997b, Jurskis et al. 1995, State Forests 1999a, 1999b, and 1999c) and individual consultants such as Gilmour (1982, 1983, 1985, 1987), Helman (1983, 1988), Ingwersen (1972, 1983, 1988), Keith and Bedward (1999), Mills (1996a, 1996b and 1999), and Taws (1997). These field surveys datasets were then sorted into four categories of data and classified according to their major roles in the project (Table 1).

Category I data, comprising full floristics with cover abundance samples, were used in the analysis and derivation of vegetation ecosystem groups. The primary classification method was based on a hierarchical classification method described in Keith and Bedward (1999) in the Eden RFA Region, using procedures developed by Belbin (1991).

The selection of a classification dataset followed Keith and Bedward (1999). Flora data selected for classification fulfilled the following criteria:

- Samples with a location on the Australian Map Grid, with a precision of at least 100 metres;
- The area of plot samples confined to 0.04 or 0.1 hectares;
- Complete list of vascular plant species within the plot; and
- Species abundances recorded on the six point Braun-Blanquet cover abundance scale or on a three point scale used by Gilmour (1982, 1983, 1985, 1987), and Helman (1983, 1988).

The Gilmour and Helman full floristic survey data, met three out of the four inclusion criteria for classification of vegetation groups and their slightly different scaling of cover was considered similar in its assessment of cover abundance on most survey plots, and comparable with survey samples assessed using the Braun Blanquet scaling method.

Category II data were used to derive a presence-absence classification. The classification method used was identical to that used with Category I data, except presence-absence measures was used instead of the Braun Blanquet scale. For comparison between the classifications developed for both category I and II data, survey data with Braun-Blanquet cover abundance data (Category I) were converted into presence-absence scale.

Categories III and IV were primarily intended for classification of canopy trees to check the quality of the mapping of canopy vegetation and support the mapping of vegetation groups. The classification method used with a combined dataset of categories III and IV was identical to that used with category II data.

Field Survey Methods

Survey work conducted during the CRA project was designed to fill environmental and geographical gaps across the study area to produce an equal spread of sites across the range of predefined environmental strata. In the western and northern sub-regions, the absence and/or scarcity of substantial patches of remnant vegetation with an undisturbed ground-cover, was a major limitation in sampling flora sites evenly across all environmental strata.

Table 1. Field Survey Data Categories

Data Category	Flora Survey Data Type	Project Role
I	Full floristics, cover abundance	Full Floristic classification – derivation of vegetation groups
II	Full floristics, presence/absence	Full Floristic classification – support vegetation mapping in critical geographic gaps of Category I survey data
III	Canopy only, presence/absence	Canopy classification – guide mapping of vegetation groups and check quality of API mapping, and validation
IV	Partial floristics, cover abundance	Similar role in project to category III survey data

Within identified gaps, sites were located across a variety of topographic positions to sample as much of the range of local environmental gradients as possible. Survey samples were located in areas with adequate access to maximise survey efficiency. Where possible, four locations were sought: one on a sheltered midslope, an exposed midslope, an exposed ridge and in a sheltered gully. Within restricted environmental strata, generally less than 5000 hectares, and where access was restricted, fewer sites were surveyed. Sites were positioned as close as possible to the targeted field location while avoiding ecotonal boundaries between different forest and non-forest vegetation; or heavily disturbed sites.

To reflect 'pre-1750' vegetation patterns as much as possible, less disturbed areas based on local knowledge and the expert opinion of the botanists involved, were surveyed. One of the greatest limitations in extrapolating to pre-1750 vegetation patterns, especially those mostly cleared, is unknown past disturbance.

Field survey methods followed plot-based sampling used in previous CRAs in NSW (DUAP 1999). A standard site data sheet was based on the one developed for the North-East CRA flora surveys. The survey approach included collection of floristic, structural, and physical data in a plot 20 metres by 20 metres in size, nested within a larger plot of 20 m by 50 m. This was to ensure compatibility with larger scale regional surveys of canopy species that had used quadrats 20 m by 50 m in size, while at the same time maintaining compatibility with other full floristic data collected using the smaller quadrat size. Floristic data recorded in the 20 m by 20 m plot included a list of all vascular plant species present and a visual estimation of the cover abundance of each species according to a modified Braun-Blanquet system of cover abundance classes (Poore 1955).

Details of each site were recorded, including locality description, map name, Australian Map Grid easting and northing, area name, stratification and site number. Within a 50 m by 20 m plot, physical data such as altitude, slope, aspect, horizon visibility and azimuth, soil depth and type, geology, land morphology and element and the presence of outcropping were also recorded. After completion of the survey of the vascular plants present, community structure was estimated over an area of 50 m by 20 m in size. The structure of the vegetation in terms of the dominant vegetation layers was described, and could include an overstorey layer, up to three mid-stratum layers, and up to three lower or ground layers. The predominant growth form in each stratum, the upper and lower heights and the percent cover, as well as three most dominant species, were recorded. Growth stage of senescent, mature or regrowth categories was also estimated within the plot.

Disturbance history of fire, logging and grazing was also noted, estimating severity and time since disturbance. The accuracy of these estimates varied, depending on the apparent field evidence available, and the subjective assessment of field botanists. Finally, an estimate of the overall condition of the site was made, incorporating factors such as the degree of weed infestation as well as the species and structural diversity.

Preparation of Survey Data

Survey data (sites, floristics, and a master species list) were stored in an electronic database to allow error checking, manipulation, and retrieval for analysis. Site records were checked for geographical accuracy by comparing the relevant 1: 25 000 map sheet against site locality descriptions and grid coordinates as they appeared on the survey forms. This information was compared to the location of the site in ArcView GIS. Accuracy to within 100 m or better was generally achieved. All grid references were checked in the GIS to ensure that they fell within the Southern CRA boundary. Throughout the classification process, there were random checks of relationships between species associations and physical site characteristics such as morphology and geographic position, and corrected any errors.

Duplicate record checks were conducted in all the database tables especially the floristics table. Discrepancies found in floristics records were identified and corrected where possible or quarantined from analysis. Checks were also conducted to ensure that all species in the floristics table had either a cover abundance value or a letter P to indicate species presence.

The database was used to compile a species inventory to check nomenclatural standards and errors in field identification. Synonyms were identified and standardised according to Harden (1990, 1991, 1992 & 1993) or more recent publications. Species occurrences were compared to published geographical ranges to identify errors in identification or data entry. Where species names had simply been changed, names were updated, but in many cases a previous plant taxon may have been split into two or more new plant taxa. In these cases the geographic distribution and ecological niches of the new plant taxa were determined and site data information updated accordingly. Plant taxa were aggregated to the species level unless there was some clear geographic or ecological distinction to enable them to be consistently distinguished in the data set.

Some of the field survey data, such as Ingwersen (1992), had their cover values converted to Braun-Blanquet scores so that they could be used in the full floristics cover-abundance classification dataset. Where possible the data were referred to the original surveyor for advice on conversion to the Braun-Blanquet scoring method. Unknown species, as well as exotic species and non-vascular plant species, which had been recorded in some data sets, were masked out of the data set to be used for classification. The masking of these categories of plant species helped to remove any confounding influences of anomalous records of native plant species and the influence of non-native species data on the PATN classification.

Environmental spatial data

A variety of spatial data layers describing climate, terrain, and lithology were compiled from spatial data prepared at a mapping scale of either 1: 25 000 or 1: 100 000 (Table 2). Climate and terrain variables were derived from digital elevation data provided by the NSW Land Information Centre, using algorithms described by Hutchinson (1989). Most of the data layers were prepared at a resolution of 1: 100 000, which equates to a 100 metre grid cell size. The climate, terrain, and geology layers were collated and prepared for use in modelling of the spatial extent of vegetation groups, whereas the CRAFTI API layer was used as the primary data layer for mapping extant vegetation.

LANDSAT Thematic Mapper imagery of the whole region was acquired to facilitate the planning of field work, checking of survey data, and to assist mapping of vegetation. Two complete Landsat scenes were prepared as TIFF images, using bands 3, 4, and 5. The data projection of the remotely sensed data was set to Zone 55, AGD66, which followed the standard set in the CRA. Two LANDSAT scenes were then digitally enhanced and cut into 8 overlapping sub-scenes that covered the full extent of the study area, with the exception of the eastern end of the Jervis and the Beecroft Peninsula in the Shoalhaven area.

Air Photo Interpretation (API) and Mapping

A classification of canopy presence-absence forest data, collated and analysed by Austin and Cawsey (1996) was adapted to enable a more direct comparison between field survey data and tree canopy associations. A region-wide classification of tree canopy species formed a better basis on which to associate field survey samples with API mapping data than forest types based on Research Note 17 (Baur 1989). A correspondence table between canopy floristic codes and Austin's canopy associations was developed to guide the coding of polygons of canopy floristic types drawn on each air photographic overlay. The detail of these eucalypt forest codes can be found in a separate report (DUAP 2000a). The coding of rainforest and non-forest component of the vegetation was based on a collaborative expert agreed classification. The non-forest API codes covered the full range of non-eucalypt and non forest types in the study area: rainforest, tall shrubland, heath, swamp, native grassland, and coastal estuarine vegetation.

Structural and floristic data layers for all forested lands were derived from 1997-98 air photos at a scale of 1: 25 000 (except in the Crookwell area where 1: 50 000 scale photos were used). Contract air photo interpreters used stereoscopic equipment to delineate canopy floristics and structural information onto overlays mounted on 1: 25 000 scale air photographs of each 1: 25 000 map sheet. Contextual information available to interpreters included other existing vegetation mapping and survey data. Familiarisation and fieldwork was limited to two to three days per 1: 25 000 mapsheet, depending on the coverage of native vegetation, the difficulty of access, and the extent of previous API work. Contractual constraints confined the API mapping to forested areas outside of forested land in urban areas, intensively developed agricultural land and rural-urban subdivisions, as well as some large pine plantations within eucalypt forest remnants. Within the fragmented woodlands and forests in the western part of the study area, additional remnant vegetation patches were mapped subsequently by a small team contracted to validate and refine the API mapping (Maguire & Hunter 2000). A comprehensive account of the API methods is contained in a separate report (DUAP 2000a).

Following scanning and rectification, the layer was merged with previous canopy floristics mapping undertaken by State Forests using Research Note 17 (Bauer 1989) and existing mapping within selected national parks and nature reserves (Doherty 1996, 1998a). The canopy floristics mapping show patches of extant forest down to 10 hectares in size and patches of non-forest vegetation down to 2 hectares. It covers most of the study area with the exception of an area north of Holbrook.

Mapping of native grasslands was not undertaken in the canopy floristics mapping, being outside the scope of the CRAFTI project. A mapping layer of pre-1750 grasslands through the South-Eastern Highlands bioregion was produced, based on earlier mapping in the southern part of the study area (Costin 1954), with additional mapping in the ACT, Gunning, Crookwell, Mulwaree, Oberon, Tallaganda, and Yarrowlumla Shires (Rhewinkel & Gellie unpubl.). Fig. 2 shows the final compiled temperate pre-1750 grasslands map. In 2005 the larger patches of temperate grasslands still surviving on Crown reserves and travelling stock routes were mapped.

Historical Parish Portion Data

State Forests of NSW (1999a) collected historical information on vegetation cover from a sample of original portion plans in parishes in the study area. Information that was collected for each portion plan included the map sheet name, parish name, portion number, plan number, date of record, notation on vegetation type and topography, point data on corner trees used to fix survey points, comments or notes and grid references of corner survey points. SFNSW (1999a) cited a study by Ryan and Stubbs (1996), which showed that where the destruction of the vegetation has been complete, the historical record, and in particular the conditional purchase plans, was indispensable in reconstructing the pre-settlement pattern of vegetation.

Where relevant, the historical data layer was used in a contextual sense by expert botanists when assigning forest types to cleared areas, but limitations of the data set included the overly broad nature of many of the early surveyor descriptions, such as *gum, peppermint,* or *stringybark,* which made it difficult to correlate with individual eucalypt species.

Table 2. Spatial data layers used in modelling and mapping (adapted from Thomas et al. 2000)

GIS Layers	Resolution of Data
Climate	
Evaporation Average	1: 100 000
Precipitation Annual Average	1: 100 000
Precipitation of the Coldest Quarter	1: 100 000
Precipitation of the Driest Period	1: 100 000
Precipitation of the Driest Quarter	1: 100 000
Precipitation of the Warmest Quarter	1: 100 000
Precipitation of the Wettest Period	1: 100 000
Precipitation of the Wettest Quarter	1: 100 000
Precipitation Seasonality	1: 100 000
Temperature (Maximum) of the Warmest Period	1: 100 000
Temperature (Mean) of the Coldest Quarter	1: 100 000
Temperature (Mean) of the Driest Quarter	1: 100 000
Evaporation Average	1: 100 000
Precipitation Annual Average	1: 100 000
Precipitation of the Coldest Quarter	1: 100 000
Precipitation of the Driest Period	1: 100 000
Precipitation of the Driest Quarter	1: 100 000
Precipitation of the Warmest Quarter	1: 100 000
Precipitation of the Wettest Period	1: 100 000
Precipitation of the Wettest Quarter	1: 100 000
Precipitation Seasonality	1: 100 000
Temperature (Maximum) of the Warmest Period	1: 100 000
Temperature (Mean) of the Coldest Quarter	1: 100 000
Temperature (Mean) of the Driest Quarter	1: 100 000
Temperature (Mean) of the Warmest Quarter	1: 100 000
Temperature (Mean) of the Wettest Quarter	1: 100 000
Temperature (Minimum) of the Coldest Period	1: 100 000
Temperature Annual Mean	1: 100 000
Temperature Annual Range	1: 100 000
Temperature Average	1: 100 000
Temperature Average Maximum	1: 100 000
Temperature Average Minimum	1: 100 000
Context	
Rivers and Streams	1: 100 000
Roads and Easements	1: 25 000
Insolation	
Solar Radiation Annual Total (11 month)	1: 100 000
Solar Radiation of the Coldest Quarter	1: 100 000
Solar Radiation of the Driest Quarter	1: 100 000
Solar Radiation of the Warmest Quarter	1: 100 000
Solar Radiation of the Wettest Quarter	1: 100 000
Solar Radiation Seasonality	1: 100 000
Lithology & Soils	
Lithology divided into 5 broad groups	1: 100 000
Lithology divided into 13 groups based on mineralogy and geomorphology	1: 100 000
Soils Landscapes Mapping	1: 100 000
Acid Sulphate Soils Mapping	1: 25 00
Terrain	
Digital Elevation Model	1: 25 000
Digital Elevation Model	1: 100 000
Aspect	1: 100 000
Distance from the Coast	1: 25 000
Ruggedness (3) - Standard Deviation of Elevation Values within a 1: 100 0000m window around the cell	1: 25 000
Skidmore Index (position on a slope from ridge to gully)	1: 25 000
Slope (degrees)	1: 25 000
Topographic Position of a cell in relation to the mean of a 250m window around the cell	1: 25 000
Topographic Position of a cell in relation to the mean of a 500m window around the cell	1: 25 000
Topographic Position of a cell in relation to the mean of a 1000m window around the cell	1: 25 000
Wetness Index (volume of water draining into a cell, adjusted for ability to retain water due to slope)	1: 100 000
Vegetation	
Eastern Bushlands Vegetation Database (EBDB) (NPWS 1995)	1: 100 000
API Mapping of Canopy Floristics – State Forests Data (SFNSW 1989)	1: 25 000
API Mapping of Canopy Floristics – CRAFTI Data (DUAP 2000a)	1: 25 000
API Mapping of Canopy Floristics – CSIRO Data (Doherty 1996, 1997, 1998a, 1998b);	1: 25 000
API Review of CRAFTI Mapping Nicholas Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and EcoGIS (2002, 2004a, 2004b, 2004c)	1: 25 000

Classification

Classification of the data was undertaken using hierarchical classification techniques (Belbin 1991). The approach to classification was based on methods described by Keith and Bedward (1999). The analyses were carried out using the PATN computer program (Belbin 1994). Dissimilarity between samples was calculated using the Kulzynski coefficient applied to un-standardized cover-abundance data. Clustering of samples into a hierarchical classification used the unweighted pair-group arithmetic averaging technique (UPGMA). The initial number of vegetation classes within the classification dataset used in this project was determined using the homogeneity program (Bedward 1999). This program measures the extent to which further splitting of groups yields improved homogeneity of groups.

A dendrogram of the classification analysis was used to view the results and to refine the classification. Appendix 1a on the CD-ROM provides a summary view of the final classification, based on a grouping of the vegetation groups into vegetation mapping classes. The suggested vegetation groups in the classification were evaluated according to three criteria: the groupings of samples made sense floristically and spatially; the groups were readily identifiable in the field; and the groups related to the vegetation patterns apparent in the landscapes of the study area. The first step was to check that each group was floristically distinctive. The second step involved a spatial assessment of each vegetation group. Further splits were

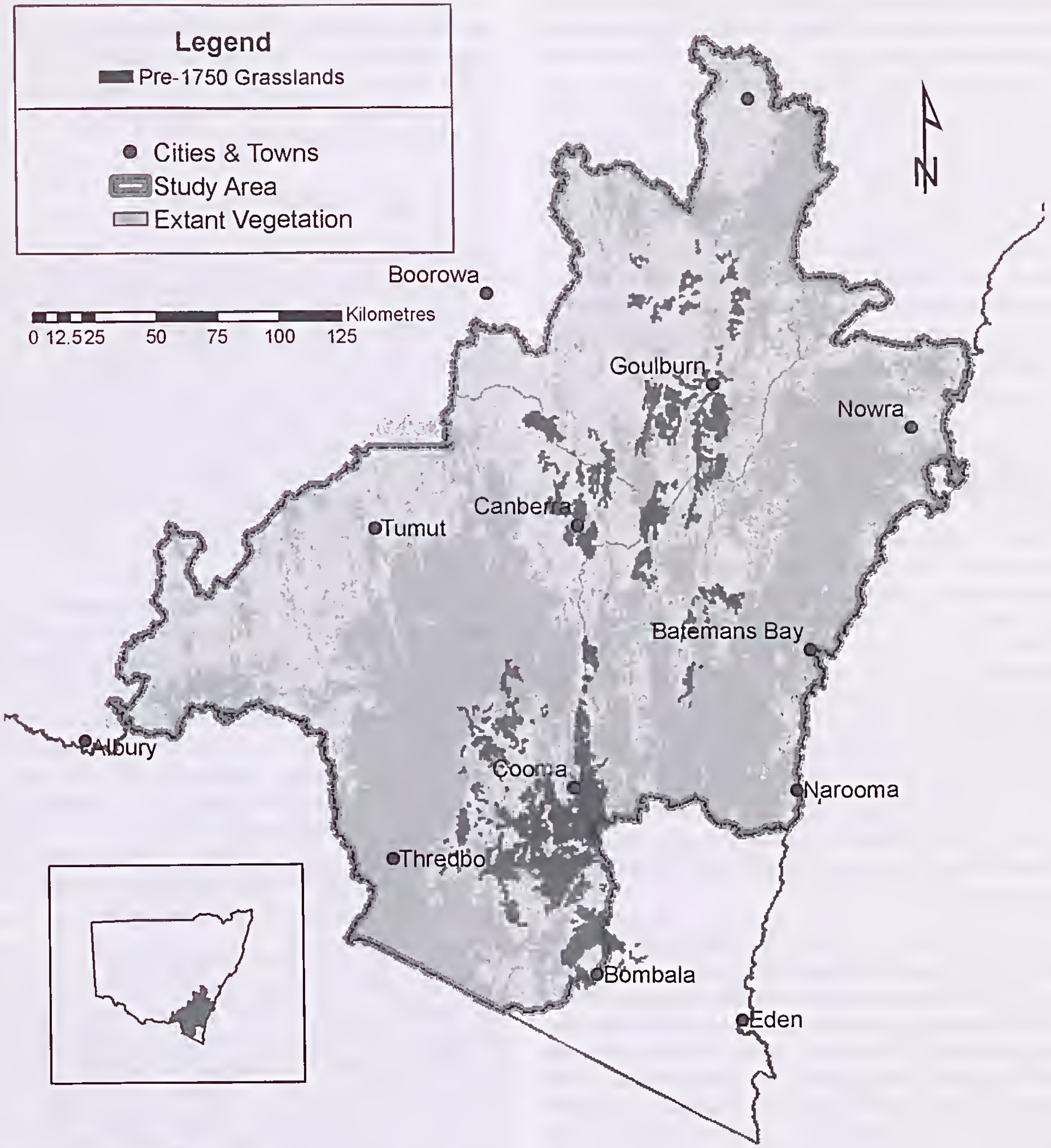

Fig. 2. Map of Pre-1750 Grasslands

made if sub-groups were floristically distinct and spatially or ecologically distinct. The distribution of samples of each vegetation group was also checked at the same time within Arcview GIS to reveal the location of the samples in relation to geology, terrain and exposure. The floristic composition of geographic outliers of the vegetation samples were checked within the site floristics database to determine if these samples belonged to other vegetation groups. A vegetation group was further split if it contained a clearly defined sub-group at a slightly lower level in the dendrogram tree. This was only undertaken where the identified sub-group, and the remainder of the original broader vegetation group could be readily related to environmental variables and mapped, or had previously been identified and mapped, and as such, met the JANIS requirements for a forest ecosystem. In some instances some closely related groups were lumped if they could not be related to geology or terrain.

Patterns of elevation, lithology, exposure, and other topographic variables were related to the spatial distribution of samples of each vegetation group on the GIS. For example, if the samples of a vegetation group, such as Yellow Box Grassy Woodlands, were found within the expected range of that vegetation group, such as on valley floors with richer soils, then those relationships were used to map that vegetation group. This process was repeated for each vegetation group until all groups had been checked on the GIS. Where there was no recognisable relationship in the distribution of the sites of a vegetation group on the GIS, further investigations of possible splitting or lumping of that group were undertaken. Checks on the floristics of that sample were further undertaken to identify any field identification or nomenclature errors. The first two iterations in the classification and checking of vegetation of groups on the GIS, revealed some vegetation groups with no obvious spatial pattern. This necessitated some revision of species nomenclature and exclusion of field survey samples with errors in field identification or with low numbers of native species present.

An iterative classification and validation process was followed by which classification was checked and errors in field identification and nomenclature removed, leading to a usable and stable classification of field survey data. Small errors in the identification of common species appeared to affect the vegetation classification. Where errors were suspected, the plant species and their cover abundances were investigated. If errors were found, any suspect plant identifications and distributions were checked with Flora of NSW (Volumes 1–4), and with other field botanists. Amendments were made to the original database file. The PATN analysis was re-run and the positions of sample sites were checked on the dendrogram, to see if the changes made any differences to the results. There were a few instances where anomalous groups that either made no geographic sense or had no obvious indicator species were formed. The sites in these anomalous vegetation groups were either reallocated to other vegetation groups or were not used in the vegetation mapping.

After satisfactory relationships between each of the vegetation groups and geology and terrain were found on the GIS, the iterative classification process was ended. Every site within the PATN Dendrogram was assigned its final vegetation number and the FIDEL program was run to provide a final profile of species found in each vegetation group. A file containing all the floristic samples allocated to vegetation groups in the final classification was then imported into the GIS for use in the vegetation mapping across the study area. The groups derived from this final classification step then were defined as *vegetation groups*, for the purposes of mapping, description, and reporting. In the original version of the vegetation mapping, these were termed forest or non-forest ecosystems, depending on whether they were forest or non-forest vegetation (Thomas et al. 2000).

A further classification of the vegetation groups into vegetation classes was undertaken using the same method to derive the primary classification (Appendix 1a on the CD-ROM). Instead of the field samples being treated as objects, a cluster analysis was performed on the vegetation groups to lump the vegetation groups into broader vegetation types. This further analysis produced vegetation classes that became the next level in the vegetation hierarchy. The vegetation classification of the study area could now be analysed or viewed at two levels instead of one created from the original cluster analysis. To complete the hierarchy, a third level vegetation formation was added to conform to the state-wide classification of Keith (2004).

Description of Vegetation Groups

The FIDEL software program (Bedward 1999) was used to profile indicator species of groups at any level within a vegetation classification. This program calculates the relative median cover-abundance and frequency of occurrence of plant species within and outside a vegetation group. The default cut-offs in the FIDEL were used to define the FIDEL output values. The default cut-offs were attribute scores set at the 50th percentile; group score cut-offs set to a cover abundance of 2 and group frequency of 50%, non-group scores set to a cover abundance of 2 and group frequency of 50%. Table 3 summarises the definitions of indicator species within vegetation groups.

An indicator or diagnostic species has high relative frequency within the Target Vegetation Group and a relatively low frequency in other vegetation groups. These plants species are usually described as Positive Species. Plant species which are described as Negative or Constant are considered unreliable indicator species. In some instances, species that occurred at a frequency between 30 and 50% were still regarded as useful indicator species, even though FIDEL labelled them as uninformative. These are described as 'Less Informative' species in Table 3. When combined with 'Positive Diagnostic' indicator species they contribute to the description and profile of a vegetation group.

Based on the information summarised in the FIDEL file, a description of each vegetation group was derived. The vegetation groups were assigned vernacular names following the conventions of Keith and Bedward (1999). The last part of the name describes the vegetation structure, such as rainforest, forest, woodland, scrub, heath, swamp, or grassland. The name may include a place name if it is found in a distinct part of the study area. A description of the understorey is generally included to give a more complete description of the vegetation group.

Descriptive profiles of vegetation groups, the first level in the hierarchy, were produced to enable identification of these in the field. These vegetation profiles are available on the CD-ROM accompanying this paper (Appendix 5). Each profile includes information about the floristic composition, structure, habitat, and occurrence of each ecosystem. Floristic data is presented in a table showing vegetation group frequency and cover-abundance of each species within the described unit, together with its frequency and abundance in all the other vegetation groups. Fidelity classes in the table describe possible indicator species in each vegetation group.

The naming convention of the second level in the hierarchy, the vegetation class, is based on regional descriptors and levels of moistness in the understorey, where appropriate to give more detailed vegetation descriptions that reflect the environmental and physiographic conditions of that vegetation class. A regional descriptor was based on botanical regions, such as South Coast, Southern Tablelands, and South-West Slopes. If a vegetation class fell within a particular part of the study area, it was given a sub-regional name descriptor, such as Lower Snowy or Morton Plateau to help with locating that vegetation class within the study area. Finally a vegetation structural descriptor completed the description of the vegetation classes, using commonly used terms for vegetation formation or sub-formations, such as rainforest, moist eucalypt forests, ash type eucalypt forests, montane eucalypt forests, dry shrub eucalypt forests, grassy eucalypt woodlands or forests, grasslands, heathlands, and shrublands, swamps and swamp heaths, sub-alpine and alpine herbfields and ferns, and coastal vegetation. The term moist shrub or layered shrub forest replaces the term wet sclerophyll, as some forests in this formation can have a variety of understorey types. For example Vegetation class 2c, Moist Layered Shrub Forest, has a mixed layered understorey, comprising rainforest, broad and fine leaved shrub plant species. A second example is vegetation class 2d, Tableland Grass/Fern Forest, has or a mixed grassy or ferny ground layer, with a layer of scattered shrubs, depending on the site and past disturbance.

The third and highest level in the hierarchy of vegetation classification is the vegetation formation. The naming convention for a vegetation formation follows of Keith (2004), with some additional formations to cover Grassy Forests, and Montane Tablelands Forests, Wet Heaths/Swamps, Vegetation on Rock Outcrops, Sub-alpine Grassy Forests, and Riparian Forests. The Montane Tableland Forests are neither grassy nor shrubby and fall into a category between Wet and Dry Sclerophyll Forests. Coastal and Tableland Grassy Forests are termed Grassy Woodlands in Keith (2004). In the study area the Coastal and Tablelands Grassy Forests have a forested rather than a woodland cover. In places with higher levels of clearing and disturbance, the current forested cover may have been reduced to a woodland state. These Grassy Forests are distinctively different from the Grassy Woodlands found further west on the tablelands and south-west slopes.

Mapping of extant vegetation

To facilitate mapping, the study area was divided into three subregions based on operational regions of State Forests of NSW and modified somewhat to conform to bioregions. The Commonwealth and State Governments adopted these sub-regions as negotiation regions for the RFA. The sub-regions were:

- **South Coast** sub-region, encompassing State Forests of NSW' hardwoods region, extending west to the Monaro Highway and including southern part of Wingecarribee and Kiama local government areas;
- **Western** sub-region, encompassing the State Forests of NSW' hardwood region in the Riverina and including the ACT;
- **Northern** sub-region, covering the southern Central Tablelands, and the northern half of the Southern Tablelands.

The mapping method is based upon an expert knowledge system of vegetation mapping that correlates the vegetation groups, defined in the cluster analysis, with environmental spatial data. The spatial distribution of each vegetation group was related primarily to the CRA forest type layer (CRAFTI) which was used as the primary mapping layer for mapping existing vegetation. Other key environmental data to guide the mapping were geology, elevation, aspect, and topographic position. The Landsat Thematic Mapper (TM) layer was used as a photographic image on which all the key environmental layers and classified survey data were overlain. The patterns of dry and wet sclerophyll forest were clearly visible and in most cases matched the lines drawn by air photo-interpreters to distinguish the broad vegetation types, such as rainforest, wet sclerophyll, dry sclerophyll, heath forest, grassy forests, heaths and swamps. It also became an important tool in investigating spatial patterns of each vegetation group, as it helped to differentiate between wet and dry sclerophyll sites

Table 3. Definitions of Diagnostic Species (after Keith & Bedward 1999) using frequency and cover abundance C/A

		Other Vegetation Groups		
		Frequency ≥ 0.5 and cover abundance (C/A) > 2	Frequency < 0.5 or C/A < 2	Frequency $= 0$
Target Vegetation Group	Frequency ≥ 0.5 and C/A > 2	Frequent	Positive Diagnostic	Positive Diagnostic
	Frequency < 0.5 or C/A ≤ 2	Negative diagnostic	Less Informative	Positive Diagnostic
	Frequency $= 0$	Negative diagnostic	Uninformative	-

on opposing aspects, the more productive forests on valley floors or along riparian zones, and any sharp transitions in vegetation, usually associated with geology or soil type.

The mapping method depended on an accurate and reliable air photo interpretation to produce a high quality vegetation map. The CRA forest type layer was first checked to ensure that it was a satisfactory base layer for vegetation mapping purposes using a two step process:

a) a preliminary check of air photo-interpretation of the CRAFTI layer in the office. All available mapped and site data was used to check polygon boundaries and API codes with the CRAFTI layer, using expert local and regional knowledge of the distribution of tree species;

b) field checks of API polygons, using a hard copy map version of the CRAFTI layer, as well as expert knowledge of the distribution of tree species during travel between flora surveys in the field.

An Arcview project within Arcview GIS 8.3 was created to enable mapping of vegetation against a backdrop of Landsat TM imagery and other contextual spatial data. Requisite spatial data was loaded into the view window. Data loaded into this view included:

- classified site data taken from the PATN analysis;
- remotely sensed imagery;
- environmental spatial data; and
- other contextual layers such as roads and utility easements and reserve boundaries.

The mapping sub-regions, South Coast, Western, and Northern, were then progressively mapped in that order. Small sections of a sub-region were mapped at a time to make the mapping of vegetation groups consistent within and between different sections of the sub-region. Each vegetation group in that section of the map was mapped using the sample sites allocated to that vegetation group in PATN, and by applying extensive expert knowledge of the likely spatial pattern of that vegetation group in the landscape. If there was a clear relationship between the expected pattern and the boundaries of CRAFTI polygons, then a numeric vegetation code corresponding to the vegetation group was placed in the vegetation code field of the CRAFTI layer.

Generally there was a clear relationship between the expected vegetation pattern and the CRAFTI mapping, and vegetation codes were directly assigned to the relevant API polygons. Some polygons required refining to adjust boundaries or to split into finer polygons to match the expected vegetation pattern. These changes were made in Arcview GIS and the vegetation group codes reassigned as appropriate.

Using this highly repetitive process across 3 120 400 hectares, three botanists, Phil Gilmour, Nic Gellie, and Michael Doherty completed the vegetation map of the three mapping sub-regions in three months (Table 4). The mapping of extant vegetation by this method proved to be the only efficient, consistent, and repeatable method within the time constraints imposed by the Regional Forest Agreement (RFA) process.

The three maps were amalgamated to create a uniform and consistent vegetation map across the whole Region. The most recent version of the extant vegetation map has recent national parks and nature reserves mapping overlain on the region-wide vegetation maps. Recent mapping includes the vegetation maps of new RFA reserves in the South-West Slopes, South Coast, and Far South Coast Regions of the Department of Environment and Conservation (EcoGIS, 2002, 2004a, 2004b, 2004c, Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, and 2005).

Models of vegetation

Modelling of the distribution of vegetation groups was undertaken simultaneously with the mapping of extant vegetation. The modelling was seen as a supportive process to the expert vegetation mapping of extant and pre-1750 vegetation and was used to test some of the assumptions held by the mapping experts about the distributions of vegetation groups within a regional landscape setting. The use of Generalised Additive Modelling (GAMS) was consistent with methods devised by Austin & Belbin (1982) and Yee & Mitchell (1991). A modelling software program, based on S-PLUS and Arcview GIS, was adapted for this purpose (Ferrier 2002). The modelling of vegetation groups' distributions were based on the classified site samples arising out of the classification phase of the project, as well as the detailed environmental layers (Table 2). GAM models were prepared for those vegetation groups that had been significantly cleared and that had sufficient plot data (at least 10 vegetation samples) to produce a valid model. Table 5 summarises which vegetation groups had GAM models run in each sub-region of the study area. The number refers to the map legend number of the vegetation groups.

Within this subset of vegetation groups, all the sites within a given vegetation group were assigned to presence sites, while the remaining sites in the other groups were assigned to absence sites. With up to 3400 absence sites available, the GAM models produced reasonable models when there were at least 20–30 samples assigned to presence data, with a reasonable distribution of samples assigned as absence data. Some of the models were also useful in identifying possible sites to reallocate to other vegetation groups.

The next stage of model production involved setting realistic minimum thresholds for the probability distribution for each model that would correspond to a realistic map of the pre-1750 distribution of each vegetation group. The spatial extent of a GAM model was usually constrained to the spatial extent of the sample sites within each vegetation group. Where there was an over-prediction in the spatial extent of a model, the model's minimum probability thresholds were adjusted higher to ensure that the model produced a tighter fit. In some cases the models were constrained with a geographic area mask, set by an expert botanist, to eliminate spurious predictions outside the known or expected range of vegetation groups.

Map validation

Occasional short trips were undertaken during mapping of a sub-region to confirm the vegetation patterns in recognisable problem areas. These field checks helped to compare the vegetation to the vegetation classification and evaluate the accuracy of the CRAFTI or mapping of state forests. Field trips also helped to resolve problematic areas such as geographic limits of similar vegetation groups that are separated by understorey components rather than canopy species, and are not well differentiated in the API layer. Additional full floristic surveys were also undertaken in areas identified as problematic for vegetation mapping.

To assist the office validation of the mapping, outside experts reviewed the extant vegetation map of the South Coast and Western sub-regions, and feedback and recommendations were incorporated into subsequent versions. Representatives of State Forests and the National Parks and Wildlife Service were involved in these reviews.

In the 2005 version of the extant vegetation map, more recent vegetation surveys and mapping have been used to validate the classification and the mapping. The mapping of RFA reserves on the South Coast and in the western parts of the study area have been used to validate sections of the vegetation map and to confirm the validity of vegetation groups in the vegetation classification. The Department of Environment and Conservation provided reports prepared by Nicholas Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and EcoGIS (2002, 2004a, 2004b, 2004c), which were incorporated into the current version of the vegetation map. Additional field survey information was kindly made available for the alpine areas (McDougall & Walsh in prep.) and for the temperate and grassy woodlands (Rhewinkel unpubl.).

Derivation of a Pre-1750 Vegetation Map

Two maps in GIS format were used to model the previous extent of vegetation on cleared land: maps of acid sulphate soils along the coastal strip, and soil landscapes maps throughout the rest of the study area. The acid sulphate soils layer (Murphy et al. (1998), based on detailed soil survey and mapping of acid sulphate soils of the lowland coastal areas of the South Coast, was essential for modelling the extent of previously cleared vegetation groups.

A separate CRA project, Lithology and Soil Landscape Mapping, produced a soil landscapes maps for the entire study area (DLWC 2000). This soil landscapes layer was a multi-attributed polygon coverage that used the CSIRO (1997) classification of lithology as a basis for the mapping of soil landscapes. Within cleared areas of each CRA sub-region, the soil layers were assigned to vegetation groups, based on the relationship between the broad soil landscapes and assigned API polygons on the adjoining forested area, and the overlay of GAMS. These relationships were explored visually within ARCVIEW GIS to help determine the possible distribution and extent of vegetation groups within the soil landscapes. As soil landscapes were mapped at a scale of 1: 100 000, some mapped landscapes were larger than the corresponding API polygons, mapped more finely at a scale of 1: 25 000. In these instances the detailed pattern on the extant vegetation map could not be transferred, and the most dominant vegetation group was mapped on the adjoining cleared land.

The pre-1750 vegetation map was prepared using the following GIS layers:

1. Extant Vegetation of the South Coast, Western, and Northern sub-regions
2. Pre-1750 Temperate Grasslands
3. Acid Sulphate Soils of the South Coast (DLWC 1998)
4. Soil Landscapes (DLWC 2000)

Table 4. Mapping of extant vegetation across mapping regions. The South Coast Region includes Commonwealth lands adjoining Jervis Bay and the Western Region includes the ACT.

Mapping Region	Area of Sub-Region hectares (ha)	Area of Extant Vegetation (ha)	Mapping Experts	Completion Time (months)
South Coast	1 842 600	1 255 200	Phil Gilmour and Nic Gellie	2
Western	2 912 600	1 446 700	Phil Gilmour, Michael Doherty, and Nic Gellie	2
Northern	1 436 800	418 400	Nic Gellie	1
Total Area	**6 192 000**	**3 120 400**		

Table 5. List of GAMS models (Thomas et al. 2000)

Southern Forests CRA Sub-Region	Vegetation Groups
South Coast	2, 5, 9, 15, 16, 21, 48, 57, 58, 59, 61, 62, 68, 73, 74, 75, 90, 109, 112, 113, 114, 146, 160, 161, 171, 174,
Western	76, 80, 82, 85, 97, 98, 103, 106, 107, 110, 111, 116, 117, 120, 146, 147, 153, 154, 157, 158, 160, 161, 162
Northern	15, 17, 73, 89, 90, 100, 109, 121, 113, 115, 121, 122, 125, 133, 134, 135, 116, 153, 161, 162

A sequential merging of the above vegetation layers, converted to 25 m grids, was undertaken. The pre-1750 vegetation map was compiled in the order and presence of grid cell values from each of these layers. The grid cell values were taken from the extant vegetation layer first, and then from the next vegetation layer, the pre-1750 grasslands layer, and then from the pre-1750 soils layers, until all the grid cells in the study area had a value of a vegetation group. The final merged product was checked to see if there were any missing grids or values in the final map. The pre-1750 vegetation map was recompiled after removal of unassigned polygons in the extant vegetation or pre-1750 soils maps.

Results

Audit of existing survey data

The data audit produced 9656 samples that could be potentially used in classification and mapping in the study area. Of these 2395 samples met the audit criteria for vegetation classification using full floristics cover-abundance data, plus 1415 additional samples from the South-East Forests region (Table 6). Tables 7, 8, 9, and 10 summarise the datasets.

Categories II, III, and IV were datasets from survey work carried out in the last 25 years that failed to meet criteria for the initial classification but were used for supplementary analyses to test for additional groups and to support the preparation and validation of the extant and pre-1750 vegetation maps. Previous flora surveys have centred on selected state forests and conservation reserves and catchment areas within the Brindabellas, Tinderry, Tallaganda, Deua and Budawang Ranges (Fig. 3). Smaller flora surveys have been carried out in the ACT and Monaro grasslands, Eurobodalla coastline, Jervis Bay and Beecroft Peninsular, in Kosciusko National Park, and in the Crookwell and Gunning Shires.

Field surveys

Between 1997 and 1999, CRA flora surveys added 1216 full floristic cover abundance survey samples, as well as another 359 canopy only presence-absence samples. The latter dataset was used mainly in the validation of the API layer. The surveys focussed principally on major gaps in survey effort in state forests and national parks (Fig. 3). There were also some field surveys done on Crown Land to supplement the other surveys. Private land was only surveyed with agreement from private landholders

Between 2001 and 2005, 418 additional field survey samples have been added to the survey database (EcoGIS, 2002, 2004a, 2004b, 2004c). This additional data has been used to validate the first version of vegetation classification and maps produced in 2000. Survey data from reports by Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and the P5MA mapping (Tindall et al., in prep.) are not included in the current database.

The current survey database contains 5444 full floristic survey samples with cover abundance data, of which about 4180 samples have been used in the more vegetation classification in 2005. An additional 6675 samples were also catalogued and checked that included either partial floristics data with cover-abundance scores; or canopy floristics data; or full floristics data with presence absence scoring values.

The field surveys since the audit have added another 33% of full floristic cover abundance samples across critical environmental gaps in the study area. While the extra sampling has not covered all the geographical and environmental gaps, it has provided sufficient samples for a region-wide classification to be undertaken with some

Table 6. Audited sample sites available for classification and mapping.

Data Category	Flora Survey Data Type	Southern Forests No of Samples	South-East Forests No of Samples	Total
I	Full floristics cover abundance	2395	1415	3810
II	Full floristics presence absence	612	589	1201
III	Canopy only presence absence	4442	0	4442
IV	Partial floristics cover abundance	0	203	203
Total		**7449**	**2207**	**9656**

Table 7. Full Floristic Cover-abundance Datasets (Thomas et al. 2000)

Reference	Location	No of Samples (ha)	Plot size
Southern Region			
Benson 1994	Monaro Grasslands	62	0.01
Binns 1997a	Bago & Meragle SF	102	0.1
Binns 1997b	Carabost & Woomargama SF	7	0.1
CSIRO 1999	Clyde Mountain and Escarpment	47	0.1
Doherty 1996	Tinderry NR	50	0.04
Doherty 1997	Mundoonen NR	17	0.04
Doherty 1998a	Brindabella NP	130	0.04
Doherty 1998b	Burrinjuck NR	33	0.04
Eurobodalla Shire Council & NPWS 1998	Eurobodalla Shire	30	0.04
Forward et. al. 1997	Kosciuszko NP - fire monitoring plots	49	0.04
Gilmour 1985	Deua National Park	127	0.1
Gilmour et al. 1987	Williamsdale and Mt Tennant locality in the Namadgi NP	113	0.04
Helman 1983	Clyde River and Mt Dromedary Rainforest Surveys	231	0.1
Helman 1983	South Coast Random Rainforest Survey	40	0.1
Helman et al. 1988	Upper Cotter catchment, ACT	135	0.04
Hibberd and Taws 1993	Gunning, Crookwell, Boorowa Travelling Stock Route Surveys	321	0.04
Ingwersen 1992	Namadgi NP	201	0.04
Jurskis et al. 1995	Queanbeyan/Badja EIS	112	0.1
Lockwood et al. 1997	Eurobodalla NP	55	0.04
NPA 1998	Benanderah SF	30	0.04
Sharpe 1991	ACT grasslands	30	0.01
Skelton and Adam 1994	Beecroft Peninsula	168	0.04
Steenbecke 1990	Middle Kowmung River, Kanangra-Boyd NP	150	0.04
Taws 1997	Booderee National Park	101	0.04
Togher 1996	Abercrombie National Park	32	0.04
Eden Region			
SFNSW 1999a	SFNSW - miscellaneous Eden	81	0.04
SFNSW 1999b	SFNSW Mt Pericoe Flora Reserve	24	0.04
SFNSW 1999c	SFNSW Mt Waalimma Flora Reserve	22	0.1
Dodson et al. 1988	Glenbog SF	30	Unknown
Fanning & Rice 1989	Bondi SF	50	0.1
Keith 1999	Wadbilliga - mallee heath survey	14	0.1
Keith & Bedward 1999	NPWS Eden CRA Survey	269	0.1
Keith & Bedward 1999	South-East Forests Combined Surveys since 1991	698	0.04
Keith & Bedward 1999	Eden CRA Validation Surveys	136	0.1
Williams 1997	NPWS Bermagui NR, Biamanga NP, Goura & Wallaga Lake NRs	91	0.04

confidence. The addition of the new samples has helped to validate some of the earlier mapping decisions made in the absence of good coverage of field survey samples, as well as expert field knowledge.

Vegetation classification

2273 samples from the audit were combined with the 1216 samples from the field surveys, together with a sub-set of 251 samples from the Eden dataset, selected within an adjoining buffer zone within the South-East Forests Region. It was decided to use a smaller number of samples from the South-East Forests to remove any bias in the vegetation classification from the much higher density of sampling in that region. The combined number of Southern and South-East Forest survey samples amounted to 3740 using samples with all vascular plants and cover abundance measures. This final dataset included some datasets such as Helman (1983), Gilmour et al. (1987), and Helman et al. (1988) which had comparable methods of assessing vegetation cover to that of the modified Braun-Blanquet method (Poore 1955). The authors of the original surveys were consulted about making consistent and repeatable changes to the cover-abundance scores, to make the datasets consistent with other surveys with Braun-Blanquet scoring systems.

Preliminary testing of levels of vegetation classification used classification levels between 100 and 200 groups. Homogeneity analysis (Bedward (1999) of 3740 floristic samples grouped into ascending number of groups (Fig. 4) was used to select a potential starting point in the vegetation

Table 8. Presence-Absence Survey Datasets (Thomas et al. 2000)

Reference	Location	No of Samples	Plot Size (ha)
Southern			
Clarke 1989 length transects	NSW Coastal Vegetation Survey	72	20m
Gunn et al. 1969	Queanbeyan Shoalhaven area	261	0.04
Ingwersen 1972	Black Mountain Nature Park	59	0.04
Ingwersen 1983; Ward & Ingwersen 1988	Tidbinbilla Nature Reserve	81	Presumed 0.04
Ingwersen et al. 1974	Mount Ainslie and Majura Nature Park	139	Presumed 0.04
Eden Region			
Breckwoldt and Breckwoldt 1979	Eden/Southern Coastal Vegetation Survey in Goura, Bermagui, & Bournda NRs, as well as Mimosa Rocks and Wallaga Lake NPs	374	0.04
Outhred 1986	NPWS Eden Survey of Wadbilliga NP	215	Nested Quadrats

Table 9. Canopy Floristics Survey Datasets (Thomas et al. 2000)

Reference	Survey location	No of Samples	Plot Size (ha)
Southern			
CSIRO 1999	Canopy Surveys - South Eastern NSW	3921	0.1
NPWS 1996	Tumut Interim Assessment Project	521	0.1

Table 10. Partial Floristics Cover Abundance Survey Datasets (Thomas et al. 2000)

Reference	Location	No of Samples	Plot Size (ha)
Southern			
Mills, 1996a, 1996b and 1999	Conjola, Cudmirrah, Illawarra, Jervis Bay, Kangaroo Valley, Nowra, Red Rock NR, and Ulladulla localities	182	Presumed 0.04
Mills, 1999	Coastal Shoalhaven	21	Presumed 0.04

classification. The upper inflection point in the curve (Fig. 4) occurred between 150 and 200 groups. After reviewing the classification between 150 and 200 groups, an intermediate starting point of 170 groups was selected, with the intention of adding further groups if field knowledge and data supported further splitting of some of the 170 groups.

A classification of 170 vegetation groups provided sufficient detail to show the pattern of vegetation at the scale of forest compartment, between 100 and 300 hectares in size, or equivalent to a small water catchment of similar size. This level of classification seemed to correspond to vegetation units that could be mapped at a scale of 1: 25 000 and provided sufficient detail to distinguish forest types on the basis of overstorey and understorey species that could be readily identifiable in the field. A 170 group classification appeared to fulfill the classification and mapping requirements outlined in the Introduction section. The dendrogram of the 170 group classification showed that samples from the adjoining South-East Forests region fell into similar groups classified by Keith and Bedward (1999). This meant that the vegetation groups in the study area had equivalents in the South-East Forests Region and provided inter-regional comparability in vegetation classification.

In addition to the vegetation groups classified using vegetation samples, a number of vegetation groups were derived from expert knowledge of gaps in the sampling effort. These were often in unsurveyed areas, in remote terrain, or could not be sampled adequately because of extensive clearing of native vegetation. New vegetation groups were created to correspond with those derived in previous vegetation mapping work or which corresponded with anomalies identified in either the CRAFTI layer or on the remotely sensed images (Appendix 1b on the CD-ROM)

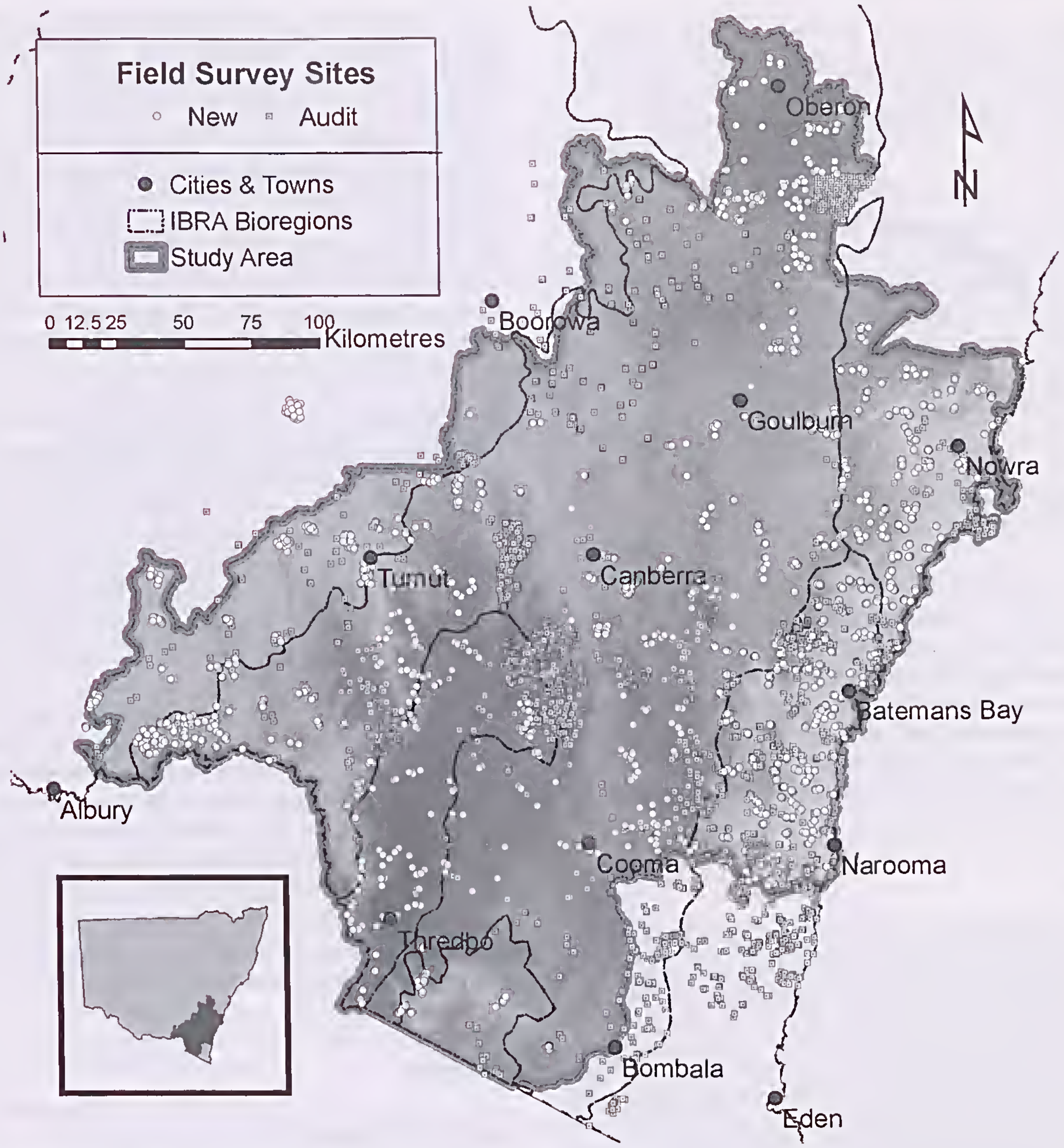

Fig. 3. Distribution of full floristic cover abundance survey samples

A lower point of inflection can be found at the level of 30 groups (Figure 4) and seemed to correspond to a much broader ecological classification, equivalent to a vegetation class (Keith 2004). This intermediate classification fell somewhere between a vegetation formation and a vegetation group. The underlying heterogeneity in some of the original 30 vegetation classes required further differentiation into separate vegetation groups to produce a classification of 48 vegetation classes. A hierarchical classification of 48 vegetation classes was created, based on a hierarchical grouping of the 170 vegetation groups derived from the PATN analysis (Appendix 1a on the CD-ROM). The rest of the vegetation groups, with group numbers greater than 170, appear in a separate table after the dendrogram (Appendix 1b on the CD-ROM). A further 6 vegetation classes were created from the expert derived vegetation groups, after matching where possible to the existing 48 vegetation classes in the classification dataset (Appendix 2 on the CD-ROM).

A complete list of the vegetation groups (Appendix 3 on the CD-ROM) includes the vegetation group numeric code; the vegetation group name; whether it was forest or non-forest; its mode of derivation in terms of classification, such as whether it was derived directly from the cluster analysis or instead was expert derived.

As well as a full floristic classification, a canopy only dataset of 9139 samples was created by merging the full floristics cover abundance and presence-absence datasets with the

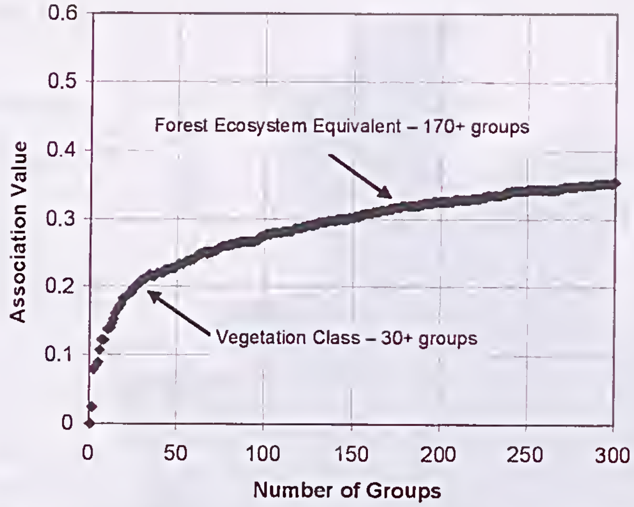

Fig. 4. Graph of Homogeneity Values, showing possible starting points in the vegetation classification

canopy only dataset (Table 11). This is less than the final number of 10238 samples available in 2005. This dataset, once classified, was a significant aid in mapping vegetation where there were few full floristic survey samples available in the more remote parts of the study area. Areas where these proved valuable included the central parts of Kosciuzko National Park, the lower footslopes of the South-East Highlands bioregion, and in the middle Shoalhaven River catchment.

Mapping

The map of extant vegetation covers 3 120 400 hectares of forests and non-forests. 193 vegetation groups were mapped on the extant vegetation map, and 199 on the pre-1750 vegetation map. 12 vegetation groups were not mapped because they occurred in small patches or as narrow lineal features and had insufficient floristic samples to map them accurately (11, 39, 72, 84, 85, 142, 155, 182, 199, 202) or they fell outside the study area (6, 52). A digital version of the extant vegetation map can be found in the mapping directory on the CD-ROM. It is produced in both Arcview grid and shapefile formats.

To map each of the ecosystems separately was considered cumbersome. Vegetation classes, which reveal some of the broader patterns and relationships of the vegetation class classes to physiography, climate and soils at regional and sub-regional scales, were mapped. Maps of vegetation classes were grouped by formation according to Keith's (2004) statewide classification. Maps of each of the vegetation formations have been prepared (Appendix 4 on the CD-ROM), in accordance with the hierarchy laid out in Appendices 1a and 1b.

Table 12 shows estimates of pre-1750 and extant areas of vegetation formations, together with other statistics on the vulnerability classes, the extent of remaining vegetation, as well as areas of each vegetation groups within conservation reserves. The most widespread and dominant vegetation formation is Dry Grass/Shrub Forest, with 1 026 800 hectares (~33% of the total extant area of vegetation). The next most common formation is Dry Shrub Forests mainly situated on the eastern side of the study area, within the South-East Corner and Sydney Basin bioregions. It covers 481 400 hectares (~16%). This is closely followed by Montane Tableland Forests with an area of 474 500 hectares (~15%), which occupies the central part of the study area, at higher elevations than the Dry Grass/Shrub Forest formation. The Moist Eucalypt Forest formation occupies a slightly lesser area of 445 800 hectares (~14%).

The vegetation formation of Heath Forests/Heathlands/Mallee Low Forests has an area of 150 300 hectares (~5%). The Sub-Alpine Forests/Woodlands formation covers an area of 112 800 hectares (4%) similar in area to that of Ash Eucalypt Forests, which covers an area of 110 700 hectares (4%). In the Alpine Area bioregion, the Alpine/Sub-alpine Complexes formation has a somewhat smaller area of nearly 80 400 hectares (~3%). Because of extensive clearing and modification of the both woodland and grassland ground cover, the once extensive vegetation formation of Grassy Woodlands and Grasslands now occupy only 89 600 hectares (~3%). It once occupied a possible area of 1 314 800 hectares previously. Vegetation on rock outcrops amounts to 48 300 hectares (2%), scattered in small pockets through out its range. Much smaller areas of the remaining formations, including Wet Heaths & Rainforests, Sedgelands, Riparian Forests, Freshwater Wetlands and Coastal Complexes, make up the remainder of the area. Their areas vary between 10 000 and 30 000 hectares in specialised habitats of the study area, ranging in areal extent between 0.3 and 1%.

Discussion

Classification and mapping

The vegetation mapping, with some extensive subsequent revisions between 2000 and 2005, has produced a map with 193 native vegetation groups. Some of the smaller and finer vegetation groups, such as linear riparian vegetation, have not been mapped. In 2000 the primary focus was to map forested ecosystems. In 2003 the scope of the study was broadened to map to cover the full range of vegetation in the study area. 418 samples were added to the original 3740 flora survey samples. The more recent classification in 2003 confirmed some of the vegetation groups suggested by botanists in the first version of the vegetation map and confirmed most of the original vegetation groups created in the first stable version of the vegetation classification in 1999. Detailed checking of vegetation in the new RFA reserves has largely confirmed the stability of the vegetation classification (Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and EcoGIS (2002, 2004a, 2004b, 2004c)).

184 mapped vegetation groups have remained stable in the classification, while the remaining 8 vegetation groups, together with some individual samples have remained inherently unstable in the hierarchical classification (e.g. 31, 59, 64, 66, 89, 97, 99, 100). These elastic and unstable samples and vegetation groups either form new groups or mix in with other samples of more stable vegetation groups. This complexity and instability in a hierarchical classification is an ever-present and complicating factor in a classification of this size.

In the South-East Forests region, Keith & Bedward (2000) identified 72 vegetation groups in an area of 550 000 hectares. By comparison the Southern Forests study area here has 193 vegetation groups for an area of vegetation of three million hectares (3 120 400 hectares). Gilmour (pers comm) contended that the classification of vegetation groups in the Southern Forests study area should have been finer than that used in the final vegetation map. A finer classification however, might make the task of identifying ecosystems in the field more difficult, because there could be a smaller range of indicator species to separate similar vegetation groups.

The larger size of vegetation groups in the Southern Forests study area may be related to the broader environmental gradients operating over the flatter topography and less diverse soils, particularly on the tablelands and western slopes. There is a higher number of vegetation groups found on the more rugged and diverse topography of the Kosciuzko and Namadgi Ranges. It is possible that the higher number of groups in the Brindabella Ranges may be due to the heterogeneity created by different flora surveys, using slightly different survey methods. Doherty (pers comm) has indicated that disturbance patterns and observer bias may have contributed to some of the extra variation and detailed ecosystems in the Brindabella area.

26 vegetation groups in the South-East Forests region (Keith & Bedward 1999) were found to be directly comparable with those in the Southern Forests study area (1, 2, 7, 13, 18, 22, 23, 28, 32, 33, 35, 47, 48, 49, 53, 54, 55, 61, 64, 134, 135, 138, 157, 164, 165, 166) (Appendix 3 on the CD-ROM).

Map accuracy

The API mapping layer was only checked during the Southern CRA in small areas (Hunter 2000). The API mapping layer often had inconsistent polygon API codes which reflected the varying interpretations made by air photo interpreters. These inconsistencies meant that assigning vegetation group codes to API polygons became quite complex and involved a great deal of checking using all available site and mapping data. In these instances the mapping expert had to use the classified floristic data and local knowledge to guide the assignment of API polygons to vegetation. Difficulties in vegetation mapping were also experienced in places where there was an inadequate coverage of site data. In these situations the mapping expert would refer to previous mapping of vegetation and reports to infer possible relationships between the API polygons and the classified site data. The canopy-only site data proved to be invaluable in places where there was no full floristic data.

The 2005 version of the vegetation map may still contain errors in places where there has been inconsistent or erroneous air photo interpretation, and where there is a scarcity of field survey data, and lack of local knowledge. One of the main limiting factors was having well stratified floristic samples across the full range of environmental gradients. Though many gaps in the geographical coverage of survey samples have been filled by ongoing survey, some areas still remain undersampled. However the average sample density across the study area has reached 0.06 samples per square kilometre, with a range from 0.01 up 0.33 samples per square kilometre (Fig. 5). The highest density of samples is found in Namadgi National Park, Jervis Bay, Bago and Meragle State Forests, and in the middle Kowmung catchment in the Blue Mountains. The sampling density is just under one third the average density of 0.18 in the South-East Forests region (Keith and Bedward 1999), and 0.2 in the survey of the Cumberland Plain of western Sydney (Tozer 2003). A sampling density between 0.1 and 0.15 samples per square kilometre in this study area would need a further 500 to 750 floristic samples. As most of the study area has less variable landscape than those in the South-East Forests region, a lower density of between 0.1 and 0.15 samples per square kilometre may be acceptable.

Since the production of the vegetation map in 2000, there has been ongoing survey, and verification of the API. Most of the new data has come from validation surveys of new RFA reserves in the Western and South Coast sub-regions. The vegetation map has also been updated in problematic areas. There has been a major update of the mapping of Grassy-Shrubby Forests, Ash Forests, Heathlands, and Alpine & Sub-alpine Complexes, indicated by the lighter grey areas in Fig. 6. In total 330 000 hectares, representing about 10% of the area has been remapped. Despite this more remapping work, the extant vegetation map requires further checking within some of the larger national parks, such as southern Blue Mountains, Kosciuszko and Morton National Parks, as well as on private and Crown lands through the northern part of the study area.

Recommended areas for further checking and revision of the map include:

- the northern sub-region in grasslands, grassy woodlands, and dry forests in the central and upper parts of the Abercrombie catchment and on the Crookwell and Goulburn plateaus;
- the western sub-region in grassy woodlands and montane grass/shrub forests, the northern part of the Cotter catchment in the ACT, a vast tract of central and northern Kosciuszko National Park, the western and eastern

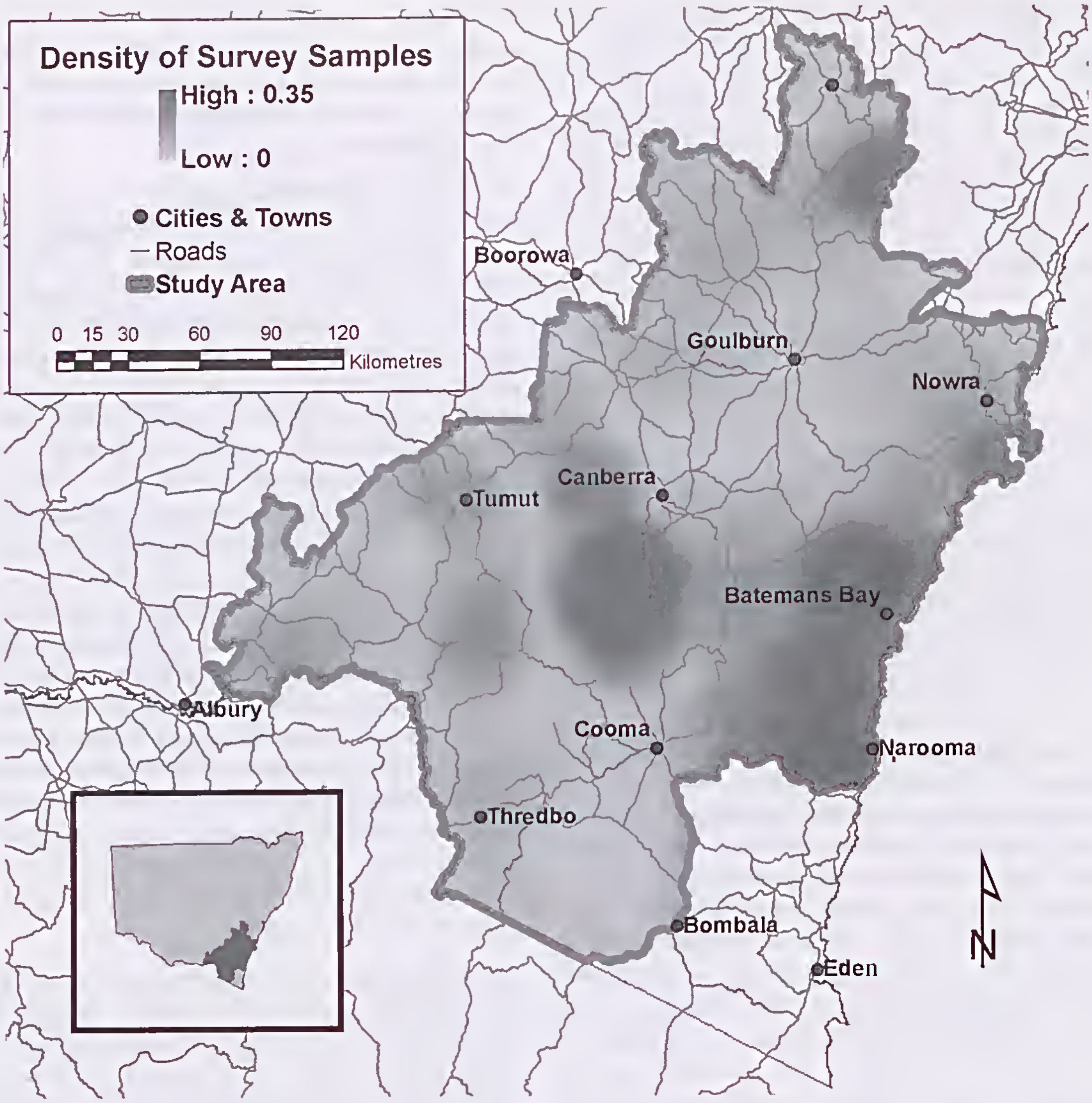

Fig. 5. Map reliability - the mean number of samples per square kilometre, within circular radii of 20 kilometres, across the Southern Forests study area

escarpments of Kosciuszko National Park, the Snowy River catchment and Delegate areas, and all through the sub-alpine and alpine complex, particularly in the non-forest areas, with particular focus on the grasslands, bogs, alpine herbfields, and feldmarks; and finally,

- the eastern escarpment sub-region in central Morton and Budawang National Parks, the grassy woodlands and grasslands through the broad valleys in Numeralla and middle Shoalhaven river catchments, and through the Numeralla and Wadbilliga ranges. Some of the additional sampling has already been completed in the northern part of the study area under the auspices of the P5MA project (Tindall et al., in prep).

Biogeographical and environmental relationships

The study area spans five bioregions, the South-east Highlands (SEH), Australian Alps (A), South-Western Slopes (NSS), South-East Corner (SEC), and Sydney Basin (SB). The bioregions reflect the varying dominant influences of geological substrate and climate that apply at a continental scale. At a regional scale the vegetation in the study area largely conforms to these bioregions with a strong gradient between warm and moist climates in the Kiama-Illawarra escarpment area, to the cooler and drier tableland plateau, and finally onto the moist and cool alpine areas. The vegetation responds to these general environmental gradients, as well as the underlying soil fertility.

1. Rainforests

The rainforest formation is found mostly in the South-East Corner bioregion comprises sub-tropical, warm-temperate, and cool temperate elements (Map 1 on the CD-Rom). Along the Southern Illawarra, Deua, and Budawang escarpments, vegetation class 1a forms mist forests in narrow sheltered gullies, on moderately fertile soils derived from Ordovician and Permian siltstones, in moderately cool temperatures and high rainfall. Gondwanan elements include plant species *Eucryphia moorei, Fieldia australis, Dicksonia antarctica,* and *Pyrrosia rupestris*. An outlier of cool temperate forest is found in moist gullies in the Geehi catchment of Kosciuzko NP, where the dominant tree is *Atherosperma moschatum*. In the milder and warmer climes below the coastal escarpment a warm-temperate/subtropical rainforest (vegetation class 1b) predominates on sites with moderately fertile soils, high rainfall, and finds full expression around the Kiama and Kangaroo Valley escarpments. Warm temperate rainforest species, such as *Acmena smithii, Ficus coronata, and Claoxylon australe,* are common throughout vegetation class 2b. *Doryphora sassafras* and *Ceratopetalum apetalum,* are more common dominant tree species in the warm temperate rainforests. In the sub-tropical/warm temperate rainforests, more northern rainforest species, such as *Dendrocnide excelsa, Baloghia inophylla,* and *Livistona australis* are represented. In the northern part of SEC bioregion, warm temperate rainforests tend to be found on the cooler sheltered slopes and aspects, whereas the warm temperate sub-tropical rainforests are found on the warmer and more exposed slopes.

2. Moist Eucalypt Forests

Moist Eucalypt Forests, sometimes adjoining rainforests, are found in four distinct bands, corresponding to areas with high annual average rainfall between 1100 and 1700mm and fertile soils, such as kraznozems and red earths. The vegetation classes, 2a, 2b, and 2c, are mainly found below the escarpments of the South-East Corner and the southern Sydney Basin bioregions. Outlying pockets of vegetation class 2a, Brown Barrel Moist Shrub Forest, are found east of Canberra in the Brindabella ranges, and around Blackjack Mountain in southern Kosciuszko, and along the Alpine Way in the Upper Murray valley catchment, where high rainfall and fertile deep soils coincide. Vegetation class 2a is found along the high parts of the South Coast escarpment between Deua and the northern Budawangs, with another area around the Robertson and Macquarie Pass areas (Map 2 on the CD-ROM).

Vegetation class 2b, South Coast and Hinterland Layered Shrub Forests, is more restricted to the sheltered slopes and gullies of the South Coast hinterland in lower rainfall areas on moderately fertile soils. Common tree species in this vegetation class are *Eucalyptus muelleriana, E. cypellocarpa, and Angophora floribunda*. The understorey can be a diverse mixture of shrubs, ferns, grasses, and forbs and may include in the shrub layer *Acacia mabellae, Synoum glandulosum, Acacia falciformis, Notelaea venosa, Pittosporum undulatum,* and *Hibbertia dentata*, as well as vines *Cissus hypoglauca, Tylophora barbata, Pandorea pandorana, and Eustrephus latifolius*. In the ground layer ferns *Pteridium esculentum* and *Doodia aspera* may be dominant, along with a scattered layer of grasses and herbs such as *Poa meionectes* and *Schelhammera undulata*.

Vegetation class 2c, South Coast/Central Coast Hinterland Moist Shrub/Fern Forests, occurs on deep soils on sheltered slopes, derived from Permian mudstones below the escarpment and along deep gullies closer to the Coast. It is probably the most productive forest type in the study area, has as dominant eucalypt species, *Corymbia maculata, Eucalyptus saligna/botryioides,* and *E. pilularis,* over an understorey of rainforest species, including *Synoum glandulosum, Elaeocarpus reticularis, Livistona australis,* as well as ferns, *Calochlaena dubia* and *Blechnum cartilagineum*.

Vegetation class 2d, Tableland Moist Fern/Herb-Grass Forests, occurs on moderately fertile soils on elevated mountain plateaus with rainfall between 1100 and 1300 mm rainfall through the South-East Highlands bioregion. This tableland forest type does not quite fit either the typical wet or dry sclerophyll categories of Keith (2004), having a *Poa* spp. tussock grasses, intermixed with moist herbs, and scattered shrubs. The dominant trees are usually *Eucalyptus dalrympleana, E. robertsonii* subsp. *robertsonii,* with sub-dominant trees of *E. viminalis*.

3. Ash Eucalypt Forests

The Ash Eucalypt Forests occupy specific environmental niches on the exposed eastern and western escarpments between 900 and 1400 metres, usually on the lee side of main ridges in better developed soils, such as kraznozems, and deep red earths (Map 3 on the CD-ROM).

Vegetation class 3a, South Coast Escarpment White Ash Shrub Forests, tends to be an ecotonal vegetation type between vegetation class 2a Brown Barrel moist shrub forest and vegetation class 7c, South Coast Escarpment Peppermint-Silvertop Ash Forests. It has as its dominant trees, *Eucalyptus fraxinoides, Eucalyptus cypellocarpa, Eucalyptus fastigata*, and *Eucalyptus sieberi*. The understorey is intermediate between wet and dry sclerophyll forest, with elements of moist shrub and heath elements intermingling in the understorey. Vegetation class 3b, Sub-Alpine Ash Shrub Forest, has an overstorey usually dominated by *Eucalyptus delegatensis*, with co-dominant tree species *Eucalyptus pauciflora,* and *Eucalyptus dalrympleana*. It has a drier understorey, comprising sub-alpine shrubs, such as *Polyscias sambucifolia* subsp. *B, Daviesia latifolia, Coprosma hirtella, Tasmannia xerophila,* and *Tasmannia lanceolata*. A more exposed, higher altitude variant of this vegetation class is vegetation group 86, whereas vegetation

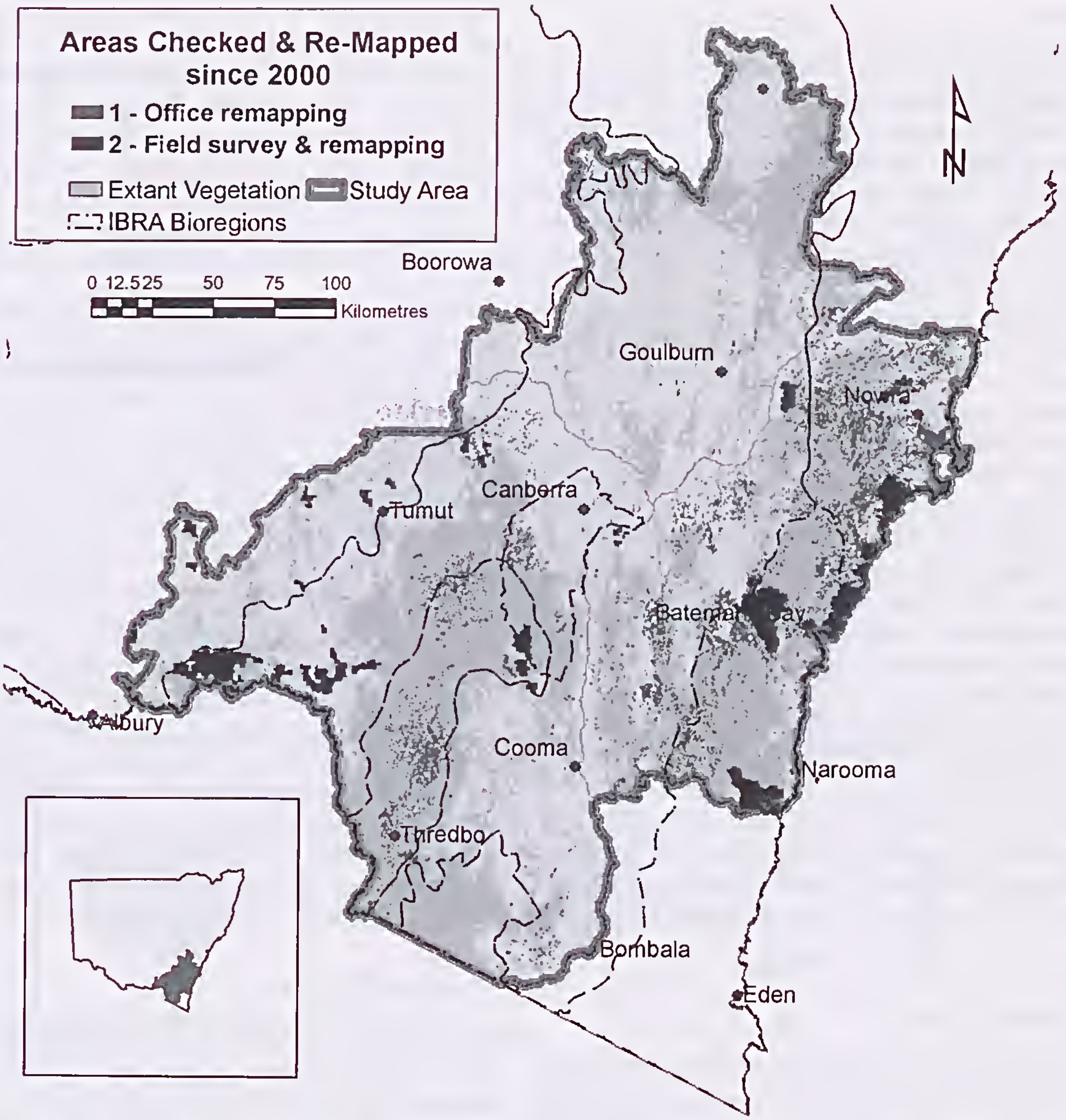

Fig. 6. Extent of mapping and validation work since 2000.

group 87 is found in more montane, sheltered slopes, mainly in the central western parts of Kosciuszko National Park. Vegetation classes 3a and 3b represent the typical fire sensitive montane tall forests, which can succumb to stand replacing fires at intervals as short as 40 and 60 years. Because of the local site conditions, Ash Eucalypt Forests are fast growing and highly productive in their respective montane and sub-alpine environments.

4. Montane Tableland Forests

A widespread formation through the higher parts of the South-East Highlands bioregion is the Montane Tableland Forests, which comprise 3 main vegetation classes, 4a, 4b, and 4c (Map 4 on the CD-ROM). Its vegetation classes tend to be found on less well developed soils in areas of slightly less rainfall than either vegetation formations 2 or 3. These forests are commonly associated with yellow podzolics and red earths on granites and metamorphic rocks. Vegetation class 4a corresponds to the more productive vegetation class Montane Narrow Leaved Peppermint Forests, which occupies sheltered slopes between 700 and 900 metres on the flatter plateau around Tumut, Black Andrew, and Woomargama to the west and north of the Kosciuszko ranges, and Blackjack Mountain in southern Kosciuszko National Park. Typical forest tree dominants include *Eucalyptus dalrympleana, Eucalyptus robertsonii* subsp. *robertsonii, Eucalyptus macrorryncha,* and *Eucalyptus bridgesiana.* The understorey comprises *Platylobium formosum* subsp. *formosum, Daviesia latifolia, Poa sieberiana* var. *sieberiana,* and *Pteridium esculentum.*

In the northern part of the South-East Highlands bioregion, vegetation class 4b, Southern/Central Tablelands Montane Shrub/Grass Forests, is a forest dominated by *Eucalyptus pauciflora, Eucalyptus dalrympleana,* and *Eucalyptus dives.* It occupies the more productive red earths in the Crookwell and Oberon plateau with moderate to high rainfall. The understorey is not that dissimilar to vegetation class 4c.

Vegetation class 4c can be found in the higher parts of the range of this formation, between *900* and *1300* metres. A complex suite of vegetation groups occupy a range of sites from exposed and rather infertile soils to deeper and moderately fertile soils. The dominant eucalypts are *Eucalyptus pauciflora* and *Eucalyptus dalrympleana subsp. dalrympleana.* In drier and lower elevations of this formation, *Eucalyptus dives* and *Eucalyptus rubida* becomes more dominant tree species, with *Daviesia mimosoides, Persoonia chamaepeuce,* and *Poa sieberiana* subsp. *sieberiana* becoming more dominant in the understorey. On moister sites the understorey changes to a moderate cover of *Poa* spp. and *Daviesia latifolia,* with a greater range of herbs, such as *Stellaria pungens, Asperula scoparia, Viola betonicifolia* subsp. *betonicifolia,* and *Acaena novae-zelandiae.*

5. Grass/Shrub Forests

The Grass/Shrub Forests occupy considerable areas of the South-East Highlands bioregion on moderate to steep slopes with red and yellow podzolic soils on sedimentary and acid volcanic rocks. They occur as far south as the lower Snowy near Byadbo, and skirt the eastern edge of Kosciuszko and the Namadgi ranges. They occupy a large part of the Numeralla ranges, as well large areas of the Crookwell and Oberon plateaus. They are also found on the western and north-western parts of the study area on steep or rolling hills above valley floors. Refer to Map 5 on the CD-ROM.

Vegetation class 5a comprises dry grassy forests found on granite batholiths and in rocky gorges of the South-East Corner and Sydney Basin bioregions. Vegetation group 54 is found on undulating slopes on clay loams derived from granite in the coastal valleys from Wallaga Lake to the Illawarra district. Tree dominants are *Eucalyptus globoidea, Eucalyptus tereticornis,* and *Angophora floribunda,* with a sparse shrub understorey of *Bursaria spinosa* and *Leucopogon juniperinus,* and a grassy understorey of *Themeda australis, Echinopogon ovatus,* and *Eragrostis leptostachya.* The gorge forests comprise vegetation groups *51* and *174,* which are found in the Araluen and Bungonia gorges. In the Araluen Valley an open grassy forest of *Eucalyptus melliodora* and *Eucalyptus maidenii* predominates while in the Bungonia gorges, *Eucalyptus tereticornis* is found in the deeper parts of the lower gorges while *Eucalyptus moluccana* and *Eucalyptus bosistoana* are common eucalypts in the open grassy forests at the top of the gorge.

A mosaic of vegetation classes 5b, 5c, 5d, and 5e found within the South-Eastern Highlands bioregion. Vegetation class 5b is found on red podzolic clay soils where average rainfall ranges between 600 and 800 mm. Trees dominants include *Eucalyptus mannifera, Eucalyptus dives, Eucalyptus rossii,* and *Eucalyptus macrorryncha,* with a common ground cover of *Daviesia leptophylla, Joycea pallida, Poa sieberiana* subsp. *sieberiana,* and *Gonocarpus tetragynus.* Vegetation class 5c is a western and northern variant of vegetation class 5b, occupying the transition between the western Southern Tablelands and the South-West Slopes. Dominant tree species in unit 5c are *Eucalyptus macrorryncha, Eucalyptus nortonii,* and *Eucalyptus polyanthemos,* over an understorey of mixed grasses and herbs, such as *Danthonia spp, Elymus scaber, Hydrocotyle laxiflora, Daucus glochidiatus, Gonocarpus tetragynus* and *Lomandra filiformis* subsp. *coriacea.* Vegetation class 5d, Central Southern Tableland Dry Grass Forests, contains a diverse range of vegetation groups which occupy the valley floors and slopes on heavier clay podzolics and yellow earths. The dominant eucalypts of this class are *Eucalyptus dives, Eucalyptus rubida, Eucalyptus bridgesiana, Eucalyptus viminalis,* and *Eucalyptus pauciflora.* Common species in the understorey include grasses *Themeda australis, Poa sieberiana,* and *Dichelachne spp,* as well as low shrubs, *such as Bossiaea buxifolia* and *Pultenaea procumbens.*

6. Grassy Woodlands and Grasslands

The Grassy Woodlands and Grasslands are found principally in the flatter lower valleys of the South-East Corner and South-West Slopes bioregions in areas of rainfall between 600 and 800 mm (Map 6 on the CD-ROM).

Vegetation class 6a, Lower Snowy White Box Woodland, is a distinct unit found in the lower Snowy gorges on shallow soils on granitic and metamorphic rocks in rainshadow areas below 650 mm annual average rainfall. The forest canopy comprises *Eucalyptus albens* and *Callitris glaucophylla,* with a sparse understorey of grasses *Themeda australis* and *Austrostipa* spp., along with scattered shrubs of *Acacia deanei* subsp. *parvipinnula, Chrysocephalum* spp. and *Lissanthe strigosa.* Vegetation class 6b is found on the western side of the Kosciusko ranges, on the extreme edge of the study area in the South-West Slopes bioregion, on moderately fertile clays on undulating terrain from Holbrook up to Boorowa Shires. An open tree canopy of *Eucalyptus albens, Eucalyptus blakelyi,* and *Eucalyptus polyanthemos* subsp. *polyanthemos,* overtops a grassy ground layer of *Microlaena stipoides, Danthonia racemosa* var. *racemosa,* and *Austrostipa scabra* subsp. *scabra.*

Vegetation class 6c, Southern Tablelands Yellow Box/Apple Box Grassy Woodland, is found in the central and central northern parts of the South-East Highlands bioregion on red and yellow podzolics on sedimentary rocks. A woodland cover of trees *Eucalyptus blakelyi, Eucalyptus melliodora,* and *Eucalyptus bridgesiana* overtop a grassy understorey of *Themeda australis, Danthonia racemosa* var. *racemosa, Microlaena stipoides* var. *stipoides,* and *Austrostipa scabra* subsp. *falcata.*

Vegetation class 6d, Temperate Grasslands, have been included in this vegetation class as they show close similarity to vegetation class 6c in the vegetation classification. Within this class, there are two distinct sub-regional groups, the Monaro Grasslands comprising vegetation group 158 in the Cooma-Monaro district, and vegetation groups 152, 153, and 157 in the Canberra and Yass localities. Common species found in both sub-regional groups include *Themeda australis, Poa sieberiana* subsp. *sieberiana, Danthonia caespitosa, Chrysocephalum apiculatum, Geranium solanderi* var. *solanderi,* and *Calocephalus citreus.* Vegetation class 6d is commonly found on the Monaro plains and through the Canberra region, on red podzolic soils derived from basalt or sedimentary siltstones, where frosts are reasonably common, and the average annual rainfall varies between 500 and 700mm.

7. Dry Shrub Forests

Dry Shrub Forests dominate in the eastern part of the study area, principally in the South-East Corner and Sydney Basin bioregions (Maps 7.1 and 7.2 on the CD-ROM). Despite the relatively high rainfall these areas receive, the low fertility and water holding capacity of the shallow soils limit growth of more lush and taller plants. The Dry Sclerophyll Forests formation is made of 9 different heterogeneous vegetation classes that reflect the diversity of overstorey and understorey species and life forms, mainly reflecting the drier and more infertile soil types.

Vegetation class 7a, South Coast/Hinterland Dry Shrub Forests, is primarily found on shallow yellow/orange infertile podzolics on dry bare ridges at elevations between sea level and 700 metres. The average rainfall varies between 850 and 1100 mm. Common tree species in this vegetation class are *Syncarpia glomulifera, Corymbia gummifera, Eucalyptus agglomerata* and *Eucalyptus sieberi,* overtopping a sparse cover of shrubs *Acacia obtusifolia, Oxylobium ilicifolium, Leucopogon lanceolatus,* and in the ground layer *Platysace lanceolatus, Entolasia stricta, Joycea pallida,* and *Dianella caerulea.* On the more undulating slopes and ridges, closer to the South Coast, vegetation class 7b can be found on yellow podzolics derived from metamorphic sediments and Permian siltstones. Common tree species in this vegetation class are *Corymbia maculata, Eucalyptus longifolia, Eucalyptus muelleriana,* and *Eucalyptus paniculata* subsp. *paniculata* Typical understorey species include *Allocasuarina littoralis, Oxylobium ilicifolium, Platysace lanceolatus, Hardenbergia violacea,* and grasses *Entolasia stricta, Poa meionectes,* and *Imperata cylindrica* var. *major.* Towards Jervis Bay and the lower reaches of the Shoalhaven River, an interesting and diverse vegetation class 7c, South Coast Mixed Species Dry Shrub Forests, can be found on yellow earths and podzolics on clay rich sedimentary rocks. The overstorey commonly has *Eucalyptus punctata, Eucalyptus eugenioides, Eucalyptus pilularis,* and *Corymbia maculata,* while the understorey has the tall shrub *Allocasuarina littoralis* as a common feature, and common small herbs and grasses, including *Brunoniella pumilio, Entolasia stricta, Lagenifera gracilis,* and *Gahnia radula.*

Vegetation class 7d, Coastal Bangalay /Blackbutt Dry Shrub Forests, is found on pockets on coastal dune deposits around Jervis Bay and Moruya on sandy podzolic soils. The forest overstorey comprises *Eucalyptus botryoides, Eucalyptus pilularis,* and occasionally *Corymbia gummifera* in the Jervis Bay area. The understorey has tall heath shrubs *Banksia serrata, Banksia integrifolia, Monotoca elliptica,* and *Acacia longifolia* subsp. *sophorae* closer to the beach. The ground layer is usually a bracken/grass understorey, comprising *Pteridium esculentum, Lomandra longifolia,* and *Imperata cylindrica* var. *major,* as well as *Lepidosperma laterale* and *Gonocarpus teucrioides.*

Along the boundary between the coastal and the South-Eastern Highlands bioregions, vegetation class 7e, South Coast Escarpment Peppermint-Silvertop Ash Forests, occurs on high ridges and plateaus, on red podzolic soils on Ordovician fine sediments, usually in areas of moderately high average rainfall between 900 and 1100m. The dominant trees are *Eucalyptus dalrympleana* subsp. *dalrympleana, Eucalyptus radiata* subsp. *radiata,* and *Eucalyptus sieberi,* usually with a bracken understorey comprising *Pteridium esculentum,* and other heath and grass-like species such as *Oxylobium ellipticum, Leucopogon lanceolatus* subsp. *lanceolatus, Dianella tasmanica,* and *Lomandra obliqua.* Within the Kanangra and Coxs River Gorge country, vegetation class 7f occupies steep ridges and slopes on Devonian sediments below vegetation class 7e, in areas of average annual rainfall between 800 and 950 mm. Common tree species are *Eucalyptus punctata, Eucalyptus blaxlandii, Eucalyptus agglomerata, Eucalyptus tereticornis,* and *Eucalyptus melliodora.* This dry forest type has scattered shrubs, such as *Olearia viscidula, Persoonia linearis, Stypandra glauca,* and herbs *Pratia purpurascens* and *Gonocarpus tetragynus.* Further to the south, vegetation class 7g represents a complex mixture of forests dominated by *Eucalyptus sieberi, Eucalyptus agglomerata,* and *Eucalyptus dives.* This type occurs on yellow podzolic soils on undulating topography on low fertility sediments in areas with average annual rainfall between 700 and 900 mm. The understorey is usually an open heath understorey with common species such as *Allocasuarina littoralis, Lomatia silaifolia, Dianella revoluta* subsp. *revoluta,* and *Entolasia stricta.*

Outliers of the dry shrubby forest formation occur further to the west on the western escarpment of Kosciuzko. These include vegetation class 7h, Western Southern Tablelands Dry Shrub Forests, which is found on the steep rocky slopes above the Tumut River. Vegetation class 7i, South-West Slopes Red Ironbark Dry Shrub/Grass Forests, is found further to the west on raised foothills of the South-Western Slopes bioregion. These two vegetation classes occur in small pockets on shallow red podzolic soils in very specific environmental niches. Descriptions of these types can be found on the enclosed CD-ROM. These two vegetation classes represent dry sclerophyll forests that could be classified as heath forests, as the understorey can be quite dense in places.

8. Heath Forests, Mallee Low Forests, and Heathlands

Several structural formations are included on the one vegetation class as they are share a dense heath understorey either in the open or underneath a tree canopy. Heathy forests, heathlands and mallee low forests are located on infertile sediments derived from Permian sandstones or granites, mainly in the South-East Corner and Sydney Basin bioregions (Map 8 on the CD-ROM).

Vegetation class 8a, Sandstone Plateau Heath Forests, contains five closely related vegetation groups that are found on relatively poor yellow or red podzols on Permian sandstones on the Morton plateau or on Ordovician sediments in the Clyde River catchment in areas of annual average rainfall between 1000 and 1200 metres. Overstorey dominants include *Eucalyptus sclerophylla* and *Corymbia gummifera*, with *Eucalyptus sieberi* becoming dominant along the escarpment and western Morton plateau. Common shrubs include *Banksia ericifolia, Banksia paludosa, Hakea teretifolia, Leptospermum trinervium, Petrophile sessilis, Aotus ericoides*, and *Allocasuarina distyla*, along with smaller forbs and grasses, such as *Epacris microphylla* subsp. *microphylla, Actinotis minor, Entolasia stricta, Leptocarpus tenax* and *Lomandra glauca*.

The next vegetation class 8b, South Coast/Hinterland Heath/Shrublands, occurs either primarily along the coast on infertile wet shallow clay podzolic soils within reasonably close proximity to the coast or higher up on the Cambewarra and Kiama escarpments on organosols with average annual rainfalls between 1400 and 1500 mm. This class of wet heaths has *Banksia ericifolia, Hakea teretifolia, Leptospermum squarrosum, Leptospermum juniperinum, Epacris obusifolia, Epacris microphylla* subsp. *microphylla, Darwinia leptantha*, and *Dillwynia floribunda* as common heath plant species, with a diverse array of sedges and ferns present in the ground cover layer. The ground cover layer includes sedges adapted to wet impeded soils, such as *Restio fastigiatus, Lepidosperma filiformis, Leptocarpus tenax, Xanthosia resinosa, Gleichenia dicarpa, Lepidosperma forsythii*, and *Gymnoschoenus sphaerocephalus*.

An extensive area of this vegetation class is found on shallow yellow podzolic soils, in areas of average yearly rainfall between 950 and 1200mm on Permian mudstone through Morton and Budderoo National Parks. It bears close floristics resemblance to 8a, Sandstone Plateau Heath Forests. Overstorey species may include *Eucalyptus sclerophylla, Eucalyptus tenella, Eucalyptus sturgessiana, Eucalyptus langleyii*, and *Coyrmbia gummifera*. The heathy understorey may include *Allocasuarina distyla, Leptospermum lanigerum, Kunzea capitata, Hakea teretifolia*, and *Banksia ericifolia*. The ground cover may be a mixture of forbs, sedges and grasses, such as *Lepidosperma urophorum, Entolasia stricta, Lepyrodia scariosa*, and *Schoenus ericatorum*.

Vegetation class 8c, High Plateau Mallee Low Open Forests, is found on shallow infertile poorly drained organosols on the Kanangra Boyd Plateau and Murrun stock route in well defined mallee patches on Permian sandstones, with an average annual rainfall between 800 and 1000 metres. There is usually a moderately dense layer of *Allocasuarina nana*, alongside mallee clumps of *Eucalyptus stricta*, with a dense cover of *Hakea dactyloides, Banksia ericifolia, Banksia marginata, Leptospermum trinervium, Isopogon anemonifolius*, and *Playsace linearifolius*. The ground cover comprises *Carex appressa, Ptilothrix deusta, Patersonia fragilis*, and *Lindsaea linearis*.

A closely related vegetation class 8d, Eastern Montane Heath/Tall Shrubland, occurs along the western spine of the South Coast escarpment from Nerriga down to Wadbilliga National Park. The soils are usually lithosols, derived from hard quartzite or shale rocks, in areas with average annual rainfall between 700 and 950 mm. The heaths are usually found on open windswept ridges, in moderately cool climatic conditions. This vegetation class contains two vegetation groups, 134 and 135, which have a number of plant species in common. In the heath shrub layer *Allocasuarina nana* is dominant, with *Brachyloma daphnoides, Banksia canescens, Hakea dactyloides, Hibbertia pedunculata*, and *Kunzea sp C*, while the ground cover layer may have *Lomandra glauca, Stylidium graminfolium, Gonocarpus tetragynus, Austrostipa pubinodes, Lepidosperma gunnii*, and *Amperea xiphoclada* var. *xiphoclada*.

9. Swamp Forests and Sedgelands

This vegetation class comprises the swamp and swamp forests found on soils with impeded drainage, usually associated with valley bottoms and creek lines. These vegetation formations are confined to narrow wet areas usually in moderate to high rainfall areas at high elevations, on organosols which collect water from adjoining areas (Map 9 on the CD-ROM).

Vegetation class 9a, South Coast/Hinterland Swamp Forests, is found on infertile organosols overlying colluvial sandy substrates. The dominant trees are usually *Syncarpia gummifera, Eucalyptus robusta, Eucalyptus tereticornis, Eucalyptus longifolia* or *Corymbia gummifera*, with a tall shrub layer of *Melaleuca linearifolia or Melaleuca biconvexa, Melaleuca squarrosa* or *Leptospermum polygalifolium* subsp. *polygalifolium*. The ground layer may have either *Gahnia* spp. or *Gleichenia dicarpa* as dominant ground cover, as well as a range of sedges and forbs, depending on site conditions. This vegetation class contains a heterogeneous group of vegetation that has adapted to particular site conditions in the Jervis Bay area, usually related to different type of colluvium that has filled the creeklines or valley floors.

Fringing the eastern Southern and Central Tablelands escarpments is another heterogeneous swamp heath/low forest group, vegetation class 9b, which occurs on sandy organosols in shallow river flats in the middle and upper Shoalhaven catchment. This is called Eastern Tablelands Swamp Heath/Low Forests. The overstorey tree dominants are usually sparse and may comprise *Eucalyptus pauciflora, Eucalyptus viminalis, Eucalyptus rubida* subsp. *rubida* or *Eucalyptus aggregata,* with *Leptospermum myrtifolium, Leptospermum juniperinum, Epacris microphyllus* subsp. *microphyllus,* as possible heath shrubs. The ground layer usually has a range of grasses and herbs, such as *Poa sieberiana* subsp. *sieberiana, Microlaena stipoides* var. *stipoides*, and *Gonocarpus micranthus* subsp. *micranthus*, and sedges *Schoenus apogon, Lepyrodia anarthria,* and *Selaginella uliginosa* subsp. *uliginosa*.

A widespread vegetation class in the South-East Highlands bioregion is vegetation class 9c, Southern Tableland Montane Wet Heaths / Swamps. This vegetation class is found in the Upper Shoalhaven and Queanbeyan River catchments on either side of the Tallaganda ranges and further to the west in the higher montane climates of northern Kosciuzko and the ACT. The vegetation groups 123, 124, 125, and 126, are confined to creek or river flats, with deep organosols in moderate to high rainfall areas between 750 and 1200 mm, occupying a diverse range of montane and lower sub-alpine environments. Typical heath shrubs include *Baeckea utilis, Epacris paludosa, Epacris brevifolius, Leptospermum myrtifolium* and *Hakea micrantha.* The ground cover layer may have either a dense cover of *Poa labillardieri* or *Carex gaudichaudiana,* with smaller sedges such as *Restio australis* and *Empodismus minus.* The inter-tussock space may be filled with forbs, such as *Euchiton gymnocephalus, Hydrocotyle peduncularis, Hypericum japonicum,* or *Oreomyrris eriopoda.* A closely related unit, vegetation class 9d, Southern Tablelands Swamp Grasslands, is found on soils in similar climatic zones of the South-East Highlands bioregion in the ACT and further to the north in the Oberon area. It tends to have a more dominant grassy/sedge layer of *Poa labillardierii* and *Carex appressa,* with herbs such as *Acaena novazelandiae,* as well as small sedges and rushes *Carex inversa* and *Juncus filicaulis*.

The final vegetation class in this heterogeneous formation is vegetation class 9e, Southern Tablelands Swamps /Open Woodlands, which is found mainly in central and northern Kosciuszko ranges and along narrow streams through the Tumut, Tumbarumba and Woomargama districts. The soils are freer draining and are typically found in frost hollows in areas with average annual rainfall between 800 and 1200mm. The overstorey typically has *Eucalyptus pauciflora, Eucalyptus stellulata* and *Eucalyptus rubida,* in some of the low lying flats in the higher parts of the Kosciuzko, ACT, and Tallaganda ranges. The grass and sedge ground cover usually contains *Carex appressa* and a range of small grasses and forbs, including *Hydrocotyle laxiflora, Hydrocotyle peduncularis, Dichondra repens* and *Mentha diemenica.* In some cases this vegetation class is likely to have a more diverse heath and grassy ground layer, which includes heath species *Leptospermum myrtifolium, Hakea micrantha, Bossiaea foliosa, Acrotriche serrulata, Mirbelia oxyloboides, Grevillea lanigera,* as well as *Themeda australis* and *Poa* spp., and small forbs *Acaena novazelandiae, Viola betonicifolia, Dichondra repens*, and *Asperula scoparia*.

10. Vegetation on Rock Outcrops/Screes

This vegetation formation covers shrublands, woodlands, and forests on rocky outcrops and scree slopes across a wide range of climates and soil substrates in the South-East Corner, Sydney Basin, and South-West Slopes bioregions (Map 10 on the CD-ROM).

Vegetation class 10a, Sub-Alpine/Montane Rocky Heath Complex, is confined to the rocky tors and western escarpment of the Alps and has a patchy occurrence through the Scabby and Bimberi ranges of the ACT. Its dominants usually include *Kunzea muelleri, Leptospermum micromyrtus, Leptospermum namadgiensis, Kunzea ericoides, Phebalium squamulosum* subsp. *ozothamnoides*, and *Oxylobium alpestris*.

The second vegetation class 10b, South Coast/Southern Tableland Hinterland Rocky Shrublands/Forests, covers a discrete set of vegetation groups in the classification that correspond to shrublands and rocky forests on Silurian granites in the upper Snowy River to steep rocky screes on Ordovician sediments on the mid slopes of the South Coast escarpment. In the Snowy River valley average annual rainfall varies between 600 and 700 mm per annum while along the South Coast it can be between 900 and 1000 mm per annum. There is a range of tree species adapted to these rocky exposed conditions, including *Eucalyptus smithii, Eucalyptus olsenii, Eucalyptus bauerlenii, Eucalyptus blaxlandi,* and *Eucalyptus fraxinoides.* Either under canopy under moderately sheltered sites or on more exposed slopes *Acacia sylvestris, Eriostemon trachyphyllus, Phebalium coxii,* may be present. An unusual group within vegetation class 10b, can be found on rhyolite outcrops in Deau and southern Budawang National Park. *Eucalyptus stenostoma* dominates the tree canopy while the shrub layer usually comprises *Allocasuarina littoralis, Leptospermum trinervium, Phebalium coxii, Boronia ledifolia, Leucopogon setiger* with a ground cover of *Patersonia* spp. The ground cover can be quite sparse on these rocky screes.

Further to the south in the Snowy River Valley, *Acacia sylvestris* shrubland form may overlap with vegetation class 10c, Lower Snowy Acacia Shrubland / Cypress Pine Forest, which has overstorey dominants of *Acacia doratoxylon, Callitris endlicheri*, with a similar shrub layer of *Eriostemon trachyphyllus*.

On the extreme south-western edge of the study area in the South-West Slopes bioregion, vegetation class 10d, South-West Slopes Acacia Shrublands, can be found on tops of sandstone ridges, in areas of average annual rainfall between 600 and 700 mm per annum. The shrubland usually has a moderately dense tall shrub layer of *Acacia doratoxylon*, along with *Callitris endlicheri*, *Allocasuarina verticillata*, *Eucalyptus blakelyi x Eucalyptus dwyeri*, with a simplified ground cover of *Stypandra glauca*, *Gonocarpus elatus*, *Crassula sieberiana* subsp. *sieberiana*, and *Triptilodiscus pygmaeus*.

Vegetation class 10e, South-West Slopes Black Cypress Pine Forests. It is found on granitic outcrops along sections of the Murray valley between Corryong and Holbrook, and up into the lower Abercrombie river valley, north of Boorowa. Annual average rainfall varies between 600 and 700 mm per annum, which is quickly shed on the bare surfaces of these rocky outcrops. Soils are usually skeletal. Common overstorey dominants are *Eucalyptus goniocalyx*, *Eucalyptus macrorryncha*, and *Callitris endlicheri*. The understorey is usually made up of *Xanthorrhoea glauca* var. *angustissima*, *Acacia verniciflua*, *Brachyloma daphnoides*, *Dodonaea viscosa* subsp. *angustissima*, *Stypandra glauca*, *Gonocarpus elatus*, and *Lomandra filiformis spp coriacea*.

The last class in this vegetation formation is 10f, Ribbon Gum Forests on Limestone, which is found on limestone outcrops in the river catchments of the Jenolan, Kowmung, lower Goodradigbee, Deau, and Yarragobilly Rivers. Unfortunately it has not been sampled. Typically it has an overstorey of *Eucalyptus viminalis*, with a shrub layer of *Bursaria spinosa* ssp. *spinosa* and *Senecio* spp., and a matt of herbs and forbs, comprising *Dichondra repens*, *Hydrocotyle laxiflora*, *Pellaea falcata* var. *falcata*, in amongst moist grasses, such as *Microlaena stipoides* var *stipoides*.

11. Riparian Forests

The riparian forests mapped possibly represent a fraction of the actual and previous extent of the riparian forests in the study area. There are two principal vegetation classs shown in Map 11 on the CD-ROM, which are associated with wide rivers or streams in the study area. The first vegetation class 11a, River Oak Riparian Grass/Herb Forest, is associated with fast moving perennial streams (Keith 2004), and usually occurs on third or fourth order streams throughout the study area. The dominant tree is *Casuarina cunninghamiana*. The understorey and ground cover is typical of other moist riparian or valley bottom moist forests/woodlands (vegetation groups 48, 92, or 162) in the study area.

The other vegetation class 11b, South-West Slopes Grass/ Sedge Forests, is associated with streams in the South-West Slopes bioregion and comprises two vegetation groups 43 and 162. The soils in these two vegetation groups are usually derived from colluvium or alluvium and are relatively deep and moist for most of the year. Typical overstorey dominants include *Eucalyptus camaldulensis* on major rivers and streams and *Eucalyptus blakelyi* further upstream on the minor streams and flatter valley floors with perennially moist soils. The understorey usually features *Carex appressa*, *Carex inversa*, *Eleocharis* spp, *Pratia pedunculata*, and a range of forbs, grasses, and rushes adapted to temporary inundation on floodplains and on shallow riparian creeklines.

12. Sub-alpine Low Forests/ Woodlands

Sub-alpine low forests/woodlands are confined to the higher elevations of the New South Wales Alps between 1500 and 1650 metres (Map 12 on the CD-ROM). The formation of sub-alpine low forests comprises two vegetation classes. A northern rocky heathy type found on the Scabby and Gudgenby Ranges on granitic substrates is confined to a narrow environmental niche in the Southern ACT ranges. This is categorised as vegetation class 12a, Southern ACT Sub-alpine Snow Gum Heath Forest. The southern vegetation class 12b, Kosciuzko Sub-alpine Low Forest, is more widespread from south of Thredbo up into the ranges surrounding Nungar Plain. Vegetation class 12b is associated with organosols derived from a diverse range of parent materials, such as sandstones, cherts, granites, granodiorites, and acid volcanics. In the range of both vegetation classes average annual rainfall varies between 1300 and 2000 mm per annum.

These low forests are usually dominated by *Eucalyptus debeuzevillei* in vegetation class 12a and *Eucalyptus niphophila* and *Eucalyptus pauciflora*, in vegetation class 12b. The understorey in vegetation class 12a tends to have a denser cover of heath shrubs, including *Kunzea muelleri*, *Leptospermum micranthus*, *Leptospermum namadgiensis*, *Oxylobium alpestre*, *Kunzea ericoides*, and *Westringia lucida*. Vegetation class 12b on the other hand has a greater mixture of alpine heaths and grasses. The shrub layer is somewhat different to that in vegetation class 12a and usually comprises *Bossiaea foliosa*, *Olearia phlogopappa*, *Ozothamnus secundiflorus*, *Leucopogon montanus*, *Leucopogon hookeri*, *Hovea montana* and *Tasmannia xerophila*. The dominant grass and herb plants species in the ground layer may comprise *Poa hiemata*, *Poa ensiformis*, *Oreomyrrhis eriopoda* and *Stellaria pungens*.

13. Alpine and Sub-alpine Complexes

Alpine and sub-alpine complexes largely fall within the bounds of the Alpine Area bioregion (Map 13 on the CD-ROM). High rainfall, low fertility soils, and cold to cool temperatures, with a high frequency of frosts in winter lead to a relatively short summer growth period. There are currently an inadequate number of vegetation samples to describe adequately this highly heterogeneous sub-alpine and alpine vegetation. The work of McDougall and Walsh (in prep.) may help to unravel the complexity of the vegetation in this vegetation formation.

Four separate vegetation classes have been identified and mapped as complexes. Vegetation class 13a, Alpine Feldmarks, is confined to the bare snow patches and bare rocky ground at elevations above 1700 mm. Below the Alpine Feldmarks two vegetation classes 13b, Alpine/Sub-alpine Herbfields, and 13c, Alpine Bogs/Fens, dominate the more open and less well drained slopes of the Alps. In the wetter less well drained areas, vegetation class 13c, Alpine Bogs/Fens predominate. Vegetation class 13d, Sub-alpine Grasslands, is more common in the northern and eastern parts of the Alps at slightly lower elevations on grassy plains, where it can be subjected to intense frosts in winter.

14. Coastal Complexes

The coastal complex vegetation is confined to the immediate surrounds of estuaries, sand-dunes, and low lying areas adjoining estuarine lakes along the South Coast. Because of the patch size and linear shape of the vegetation groups present, it is difficult to present the information at an adequate scale to differentiate the separate vegetation classes (Map 14 on the CD-ROM).

Map unit 14a, Coastal Dune Complex comprises five separate vegetation groups, which occupy distinct zones in the fore, mid, and hind-dunes. The zonation in the dunes reflects the transition from an undeveloped sandy soil in a foredune through to a well developed sandy podzol in the hind-dune. The type of plant species present in each of the distinct dunal zones reflect the soil differentiation and salt loading coming in off the sea. Details of the floristics composition of each of these vegetation groups can be found in the detailed description of each vegetation group on the accompanying CD-ROM.

In the low lying areas above the tidal zone, vegetation class 14b, Coastal Swamp Heath/Forest Complex, is found on acid sulphate soils in semi-inundated areas. Usually these areas adjoin wetlands, dominated by species such as Phragmites communis, and areas of open water in brackish areas of freshwater estuaries. Around the edges of saline estuaries, a complex mosaic of salt marshes and mangroves interweave in intricate patterns on mudflats, reflecting the varying impact of waterlogging and salt concentration in the soils (Keith 2004). This complex of inter-tidal estuarine vegetation is mapped as vegetation class 14c.

15. FreshwaterWetlands

There are three vegetation classes of freshwater wetlands in the study area. Vegetation class 15a comprises the coastal freshwater lagoons and sand dune wetlands. Vegetation Class 15b comprises the montane lakes, such as found in the lakebeds of Lake George and Lake Bathurst. Vegetation class 15c is found in and adjoining billabongs in amongst vegetation group 43 on along the Murrumbidgee and Murray Rivers. Since none of these vegetation classes were sampled, there are no detailed vegetation descriptions. However the vegetation classes described here correspond to those in Keith (2004) where details of the characteristic species can be found.

Disturbance Regimes

Typical disturbance agents include fire, clearing, grazing, logging, drought, and predation by insects or diseases. These disturbance agents vary in their frequency, season, timing in relation to drought or rain, spatial extent, intensity, and likely combinations within each vegetation formation. These are referred to here as disturbance regimes and are summarised in Table 11 which is intended to be a guide to the general trends in disturbance regimes since European settlement.

The introduction of feral and domestic animals and exotic plants, combined with changed fire regimes or timber getting, have significantly altered the historical pattern of natural disturbance regimes of the grassy forested and non-forested ecosystems, with consequent changes in species diversity and structure of these grassy forests. Some of the Dry Shrub Forest and Moist Forests formations have probably had much less change to their historical pattern of disturbance processes. In the late 1800s, clearing associated with free selection on Crown Land, and timber getting in the early part of the 20th century converted extentive areas of old growth forest to pasture, potato farms, or regrowth forest. Early accounts referred to eucalypts of gigantic proportions in the Yarrawa Brush area near Robertson (Jervis 1962).

Dendrochronological studies (Banks 1982, Pulsford 1989) have suggested an increase in fire frequency in the sub-alpine forests and lower Snowy forests, associated with European use from 1870 to 1950. Frequent spring or autumn burning, associated with maintenance of 'green pick' for introduced stock, became an annual practice. This was in marked contrast to infrequent fires prior to European settlement. Research by Costin (1966) produced evidence of the negative impacts of frequent grazing and burning on water yield and sediment production. When grazing was excluded from the sub-alpine and alpine zones, there was a sudden reversal in the fire frequency on the alpine and sub-alpine vegetation in the Snowy Mountains. However from 1960–1980 the drier Montane Tableland Forests and the Dry Grass/Shrub Forests on the western footslopes of the ranges became the focus of more frequent intensive burning as a fire mitigation strategy. Since then, the NPWS have adopted a more conservative fire management in these forests, limiting burning to strategic property protection. The wildfires in a severe drought year in the 2002/2003 fire season were widespread, given the large numbers of dry lightning storm ignitions, and a dry continuous fuel cover over a wide area. Much of the forest regrowth in the sub-alpine forests is regrowing from lignotuberous resprouts and seedlings in heavily burnt areas.

Rabbit plagues between 1880 and 1950s were a regular feature until the introduction of Myxomatosis rabbit virus in the 1950s. These rabbit plagues also had a major impact on vegetation cover and fuel build-up, especially during droughts, and led to widespread sheet and gully erosion (Costin 1954).

Gilmour and Plumwood (1982) collated anecdotal evidence from neighbours of Budawang National Park that confirmed the frequent, chaotic, and uncontrolled pattern of burning prior to the introduction of fire permits under the 1949 Rural Fires Act of NSW. Occasional extensive hot fires were known during drought seasons such as 1913/14, 1929/30 and 1939/40. Characteristic uncontrolled spring burning on the western side of Morton, Budawang, and Deua National Parks has become much less frequent since the 1950s, with only occasional summer wildfires of smaller size than in earlier decades of the twentieth century. National parks' management from the mid 1970s has become more conservative, with burning associated with protection of life and property along national park boundaries. Occasional larger prescribed burning has occurred within parts of Deau and Wadbilliga National Parks but the gross area burnt within a ten to fifteen year period is suggesting a longer fire frequency between 25 to 40 years. Extensive and intense wildfires during El Nino drought periods could explain the lack of smaller, more numerous intervening fire events during non-drought years.

Since the introduction of exotic perennial grasses in the 1960s and 1970s, invasive perennial grasses such as Phalaris (*Phalaris aquatica*) have invaded grassy forests and woodlands adjoining improved pastures in agricultural landscapes of the South-West Slopes and South-Eastern Highlands bioregions. These grassy woodlands have lost many of their original native understorey species, and very few grassy forests in the valleys or lower slopes can be found in their original native condition on private land, on travelling stock routes, or on larger Crown Land blocks. In western lower elevations, invasive weeds, such as St Johns Wort (*Hypericum perforatum*) have spread into larger patches of grassy forests on State Forests, National Parks, and Crown Lands. Attempts to control these invasive species have been sporadic and poorly-coordinated. Fire and drought can exacerbate invasion of aggressive weeds and limited natural control agents, grazing of exotic stock, and benign neglect on public and private land, may threaten and possibly eliminate some of the more threatened natural ecosystems, particularly in the grasslands, grassy forests and woodlands.

Conservation significance and threatening processes

It is estimated that nearly 4.5 million hectares (4 447 900 hectares) of forests or woodlands covered 72% of the Southern Forests study area at the time of European settlement. The remaining 28% of vegetation was made of non-forest vegetation formations, such as tall shrublands, heaths, swamps, or grasslands (Table 12). In the last 200 years, the pre-1750 area of forests has been reduced to about three million hectares (3 120 400 hectares), about 44% of the study area, while the area of non-forest vegetation has been reduced to 428 000 hectares, about 7% of the estimated pre-1750 area. Despite these reductions however, there are still considerable areas of native vegetation, covering about 50% of the Southern Forests study area.

However the clearing and modification of native vegetation has not been uniform across the area. The vegetation formations most affected by change have been the Grassy Woodlands and Temperate Grasslands, and the Riparian and Grass/Shrub Forests. These formations are found on the more fertile and less rugged land, that provided the most suitable sites for agricultural settlement in the 19th and early 20th century. In the Shoalhaven and Kiama precincts, rainforests were cut for their timber in the 19th century, and then cleared. Considerable areas of the montane tablelands and the less productive dry grass/shrub forests were cleared for pine plantations in the Oberon and Tumut-Tumbarumba areas in the 1960s as part of Australia's commitment to self-sufficiency in wood products. The shift in population to the coast in the last 20 years has led to further clearing of significant coastal complex vegetation and the swamp forests/wet heaths, and sedgelands.

The forests in the more rugged parts have been less changed since European settlement. The least affected formations have been the high elevations Alpine/Sub-alpine Complex and the Sub-alpine Low Forests. The extent of clearing has been as low as 1–3%. Nevertheless extensive summer grazing and occasional intense fires have affected the ground-cover and soils. Severe fires at intervals between 40 and 60 years have modified the structure of the Sub-alpine Low Forests and Ash Eucalypt Forests towards a regrowth rather than an old growth form.

The Heath forests/Heathlands, as well as Vegetation on Rock Outcrops/Screes, have not been significantly cleared because of their unsuitability for agriculture or forestry, but are currently under pressures from more frequent fire regimes, particularly along the South Coast escarpment, which seems to be experiencing more frequent drought periods at the height of summer.

The production of the first vegetation map in 2000 focussed on the mapping of forest ecosystems, and did not include the mapping of extant native grasslands. The mapping of pre-1750 grasslands was undertaken to limit errors in pre-1750 forest ecosystem estimates. The 2005 version of the vegetation map now contains extant grasslands areas. Pre-1750 grassland area is estimated at 450 000 hectares, with about 12 500 hectares or about 3% remaining. The estimate of 12 500 hectares is a preliminary one, and with further field investigations, might rise to 20 000 hectares, including partially degraded natural temperate grasslands. This still represents a small fraction of pre-1750 area.

As part of the assessment of the criteria of comprehensiveness and representativeness in 1999 (JANIS 1996), experts assessed and ranked the vegetation groups. Based on the estimates of pre-1750 and extant areas, and the extent of clearing since 1750, these experts reached consensus on the rarity and vulnerability rankings of each vegetation group. The latter estimates have been since updated to reflect the 2005 version of the pre-1750 and extant vegetation map, as well as accounting for the current reserve system.

Rarity of each vegetation group was considered separately to that of vulnerability. The criterion of area less than 1000 hectares was used to identify rare vegetation groups (JANIS 1996). Because of possible errors in the estimation of pre-1750 and extant areas, this latter criterion was adjusted where local knowledge assessed some vegetation groups as being either rare or not rare. The rare vegetation groups preliminarily identified by vegetation formation: Rainforest (164, 172, 168, 197); Ash Forest (62); Grass/Shrub Forests (183); Heaths/ Heath Forests (136, 184, 200, 216); Swamp Heaths/Forests (65, 125, 126, 212); Vegetation on Rocky Outcrops (192); Alpine Complex (204, 205); Coastal Complex (195, 196); and Wetlands (188, 189, 199).

Vulnerability ranking was based on an estimated area of percentage cleared since pre-1750 (1 was considered very high vulnerability, 5 was very low). The type and significance of environmental pressures and the vulnerability of a vegetation group to those pressures were then considered. The environmental pressures considered were grazing, clearing, logging, weeds, recreational pressure, fire, urban development and hobby farming. The vegetation formation with the highest number of vulnerability class 1 or 2 scores is the Grassy Woodlands/Temperate Grasslands, with over

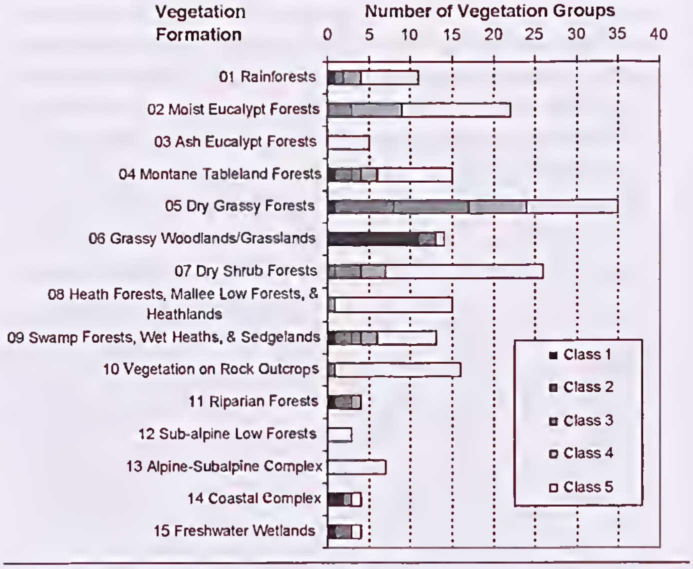

Fig.7. Vegetation formations showing vegetation groups within each vulnerability classes by vegetation formation

Table 11. Inferred historical and current disturbance regimes in the major forest formations of the Southern Forest study area

Vegetation formation	**Historical disturbance regimes (pre 1820s)**	**Settlement period (1820–1950s)**	**Current regimes (1950s to present)**
2. Wet Sclerophyll Forests	Very infrequent intense fires at 50–100 year intervals.	Infrequent fires at 15–30 year intervals during droughts. Selective timber cutting and some clearing. Sporadic insect defoliations.	Infrequent intense fires at 30–50 year intervals. Intensive timber harvesting. Sporadic insect defoliations.
4. Montane Tableland Forests	Infrequent moderate to high intensity fires at 20–50 intervals. Low levels of grazing.	Frequent low to moderate intensity fires at 5–10 year intervals. Timber harvesting, moderate grazing and extensive clearing for pasture.	Infrequent moderate to high intensity fires at infrequent intervals, more than 20 years. Moderate to high grazing pressures and timber harvesting.
5. Dry Grass/Shrub Forests	Infrequent moderate to high intensity fires at 12–30 year intervals. Low levels of grazing.	Frequent low to moderate intensity fires at 5–10 year intervals. Timber harvesting, moderate grazing and extensive clearing for pasture.	Infrequent moderate to high intensity fires at infrequent intervals, more than 20 years. More frequently burnt as part of prescribed burning programmes in the 1950s to early 1970s.
7. Dry Shrub Forests	Infrequent moderate to low intensity fires, at 10–20 year intervals, from late spring to late summer, low levels of grazing. Occasional high intensity fires	Frequent low to moderate intensity fires, at 5–10 year intervals, mainly in early Spring. Occasional intense summer fires at 21–40 year intervals. Selective timber cutting.	More frequent intense summer fires at 10–20 year intervals. Timber harvesting and low levels of grazing.
6. Grassy Woodlands/ Grasslands	Light grazing, occasional fires of moderate intensity.	Frequent fires of varying intensity. Heavy grazing, fencing and fragmentation.	Heavy grazing, infrequent fires, weed incursion. Replacement by introduced perennial grasses.
12. Sub-alpine Low Forests / Woodlands	Occasional medium sized fires of moderate to high intensity. Very light grazing.	Frequent fires of varying intensity, with occasional high intensity fires. Heavy grazing.	Occasional intense fires during drought years. Very light grazing by native animals.

11 vegetation groups in vulnerability class 1 (Fig. 7). The next most threatened vegetation formation comprises the Riparian Forests, with four vegetation group s spread between vulnerability classes 1, 2, and 3. Both these formations are found on flatter more fertile country in the study area. The much lower representation of high vulnerability classes in the remaining vegetation formations reflect the less fertile and hillier terrain of the study area, which has been less cleared and modified in the last 200 years.

The current reserve system covers 1.5 million hectares (1 565 200 hectares) and occupies 25% of the pre-1750 area. It caters well for the least vulnerable vegetation formations in the steeper, less fertile terrain, but is still missing some of the more vulnerable vegetation formations and vegetation groups (Table 12). After applying the JANIS criteria, the total target area, comprising all vegetation groups, comes to 771 100 hectares. After deducting the area of vegetation in the current reserves, there still remains about 220 600 hectares to be conserved on private land in some form.

The priority of the recent Southern Regional Forest Agreement was to transfer land from Crown Land and State Forests to formal conservation areas such as National Parks and Nature Reserves. This process largely overlooked the more vulnerable vegetation groups in the Grassy Woodlands/Temperate Grasslands and Grassy Forests formation, which are principally on private land on the Tablelands and Western Slopes, and reflects the current bias in the reserve system towards the less vulnerable vegetation formations. The remaining conservation target of 220 600 hectares includes 196 300 hectares in the most vulnerable vegetation formations. Given the extent of past clearing and ongoing modification of native vegetation on private lands, it may be difficult to attain the goal of a truly comprehensive, adequate, and representative (CAR) reserve system. Without some form of protection through conservation agreements and incentive schemes, vulnerable vegetation formations will most likely continue to degrade from the combined impacts of habitat fragmentation, weed infestation, and loss of native species.

Conclusion

The approach used to map vegetation in the Southern Forests relied heavily on air photo interpretation. This is in marked contrast to the decision-tree mapping approach of Keith & Bedward (1999) in the South-East Forests region, which relied heavily on environmental variables to predict the occurrence of vegetation. Keith and Bedward could not find relationships between classified survey data and the API mapping, and so discarded the API mapping as a modelling layer. While there is a scale difference in the size of field survey samples, relative to the size of the API polygons,

Table 12 Conservation significance of vegetation formations

Broad Formation	Pre-1750 area (ha)	Extant area (ha)	% of total extant area	% Cleared	Area in reserves (ha)	% of pre-1750 area in reserves	JANIS target not in reserves (ha)
01 Rainforests	40 100	29 700	1%	26%	15 100	38%	1 300
02 Moist Eucalypt Forests	577 600	445 800	14%	23%	240 900	42%	1 400
03 Ash Eucalypt Forests	110 900	110 700	4%	0%	90 700	82%	100
04 Montane Tableland Forests	654 900	474 500	15%	31%	310 900	47%	9 700
05 Dry Grass/Shrub Forests	2 296 600	1 026 800	33%	56%	282 900	12%	143 300
06 Grassy Woodlands/Grasslands	1 314 800	89 600	3%	93%	39 700	3%	45 400
07 Dry Shrub Forests	620 700	481 400	16%	22%	244 100	39%	5 600
08 Heath Forests, Mallee Low Forests, & Heathlands	155 900	150 300	5%	3%	109 100	70%	100
09 Swamp Forests, Wet Heaths, & Sedgelands	51 000	30 100	1%	42%	12 100	24%	4 300
10 Vegetation on Rock Outcrops	49 600	48 300	2%	3%	29 300	59%	1 800
11 Riparian Forests	53 100	11 400	0.4%	79%	3 300	6%	2 200
12 Sub-alpine Low Forests	112 800	112 200	4%	1%	107 100	95%	0
13 Alpine-Subalpine Complex	83 300	80 400	3%	3%	76 600	92%	0
14 Coastal Complex	33 000	10 200	0.3%	68%	3 200	10%	1 600
15 Freshwater Wetlands	20 100	19 000	1%	5%	200	1%	3 800
Totals	**6 174 400**	**3 120 400**	**50%**		**1 565 200**	**25%**	**220 600**

the use of field knowledge and field sampling has helped to overcome some of the potential correlation issues between the two sources of mapping data. Ferrier et al. (2002) argues the case for integrating traditional vegetation mapping and environmental layers to map vegetation communities in the North-East Forests of New South Wales. This could be considered if the API mapping in the study area could be thoroughly checked for consistency in coding and modified to match more closely the environmental gradients and natural vegetation patterns.

This method of vegetation mapping has proved to be versatile, flexible, and adaptable in a consistent and more or less repeatable manner. The methods employed have some considerable advantages over mathematical modelling techniques, such as GAMS (Austin et al. 1996) or a decision tree expert system (Keith & Bedward 1999). Its advantages in mapping vegetation include:

- production using the best available GIS and field knowledge, using intuitive and interactive GIS methods; and
- rapid revision using a wide variety of site and mapping data, as well as local and regional knowledge of vegetation.

Using their combined knowledge, a botanist and an air photo interpreter can produce a draft vegetation map simply and quickly. Using the methods described in this paper, data from further validation work can be quickly incorporated into the map, using adaptive management methods to update it.

Although the method of vegetation mapping does not adhere to the rules of strict objectivity and transparency, it does incorporate a range of field survey data, field knowledge, survey and mapping data from other research and survey reports, and iterative field validation. The method allows for ready update of both the pre-1750 and extant vegetation maps, as more flora survey and improved API mapping data become available. Since the completion of the project in 2000, the original vegetation map has been extensively checked and updated for use in fire management and management plans in new RFA and existing reserves. The continued use and adaptation of the original work demonstrates a continuing use and acceptance of this work in planning and management. With further field validation on private land, this regional vegetation map could be used in State of Environment reports of vegetation condition at levels of state, regional or local government.

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Vegetation and floristics of Warra National Park and *Wattleridge*, Northern Tablelands, NSW

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Abstract: The vegetation of Warra National Park (29° 29′S, 151° 56′E; 2041 ha in area) and *Wattleridge* (29°31′S, 151°54′E; 648 ha in area), located approximately 35 km southeast of Glen Innes and 5 km west of Mount Mitchell, within the Guyra and Severn Shires in the New England Tablelands Bioregion NSW, is described. Nine vegetation communities are defined, based on flexible UPGMA analysis of cover-abundance scores of all vascular plant taxa. These communities have been mapped based on analysis of quadrat data, air photo interpretation, substrate variation and ground-truthing.

Communities described are: (1) *Leptospermum novae-angliae* (New England Tea-tree) – *Bursaria spinosa* (Blackthorn) Riparian Scrub & Heath, (2) *Eucalyptus pauciflora* (Snow Gum) – *Eucalyptus nova-anglica* (New England Peppermint) Woodland, (3) *Haloragis heterophylla* (Variable Raspwort) – *Carex inversa* (Sedge) Herbfield, (4) *Baeckea omissa* (Baeckea) – *Leptospermum gregarium* (Swamp Tea-tree) Closed Wet Heath, (5) *Eucalyptus cameronii* (Die-hard Stringybark) – *Eucalyptus campanulata* (New England Blackbutt) Shrubby Open Forest, (6) *Eucalyptus radiata* subsp. *sejuncta* (Narrow-leaved Peppermint) – *Eucalyptus acaciiformis* (Wattle-leaved Peppermint) Woodland, (7) *Eucalyptus cameronii* (Die-hard Stringybark) – *Eucalyptus caliginosa* (Broad-leaved Stringybark) Grassy Open Forest, (8) *Eucalyptus nobilis* (Manna Gum) – *Eucalyptus obliqua* (Messmate) Tall Open Forest, and (9) *Eucalyptus obliqua* (Messmate) – *Eucalyptus nobilis* (Manna Gum) Tall Open Forest, (10) *Leptospermum novae-angliae* – *Kunzea obovata* – *Brachyloma saxicola* Shrubby Open Scrub and Closed Heath.

Of 11 communities within the area, four should be considered as threatened, while 18 taxa are considered to be of conservation significance.

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Introduction

Warra National Park (29°29′S, 151°56′E) and the nearby *Wattleridge* freehold property managed under an Aboriginal trust (29°31′S, 151°54′E) are located within the Northern Tablelands Botanical Division, 35 km southeast of Glen Innes, just north of the township of Backwater. *Wattleridge* and parts of Warra NP south of the Sara River are within the Guyra Shire. Most of Warra NP however, is within the Severn Shire whose boundaries extend to the northern banks of the Sara River. Warra NP covers 2041 ha, most of which was the former Warra State Forest (including Crown Mountain Flora Reserve) and a small Vacant Crown Land holding on the southern side of the Sara River. The Park is bounded on three sides by private freehold land and on the north side by State Forest. A national park within the Backwater area was originally proposed in 1985 by John Benson. Quinn et al (1995) highlighted the importance of this area as a hotspot for endemics and rare and threatened species, and recommended land acquisition for reservation. Further proposals were supported by Richards (1996) and Morgan and Terrey (1999) and Warra NP was gazetted in 1999. *Wattleridge* property (648 ha) approximately 2 km southwest of Warra NP, and supporting a large area of natural vegetation, was purchased by the Indigenous Land Corporation on behalf of the Banbai Traditional Owners in 1998. *Wattleridge* was formally listed as the first Indigenous Protected Area in 2001; this process included entering into a Voluntary Conservation Agreement.

This paper is based on a flora survey of Warra National Park for the NSW National Parks Service, and *Wattleridge* for the Banbai Business Enterprises Inc., to provide information for developing appropriate management strategies (Hunter 2001; Hunter 2003d).

Climate

The region receives cold westerly or southwesterly winds in winter, and rain-bearing easterly winds, and cyclonic depressions and thunderstorms in late spring and summer (RACAC 1996). Cold fronts with rain and snow often peak in June. Average yearly rainfall is between 890–970 mm in Warra National Park Areas of high elevation such as Crown and Nightcap Mountains receive higher rainfall due to fog and cloud cover. At Guyra the average maximum summer temperature in January is 24°C, and the average minimum temperature in July is 0°C. An average of 20 frosts occur annually. Cold air drainage and increased likelihood of frosts occur in river valleys.

Landform

Warra National Park and *Wattleridge* are part of the upper catchment of the Sara River which later joins the Guy Fawkes River. The Sara River runs along the northern boundary of *Wattleridge* and forms the southern boundary of Warra NP (Fig. 1). Creeks flowing north and northeast out of Warra NP are upper catchment tributaries of the Henry River which flows through to the northern sections of the Guy Fawkes River (Fig. 1).

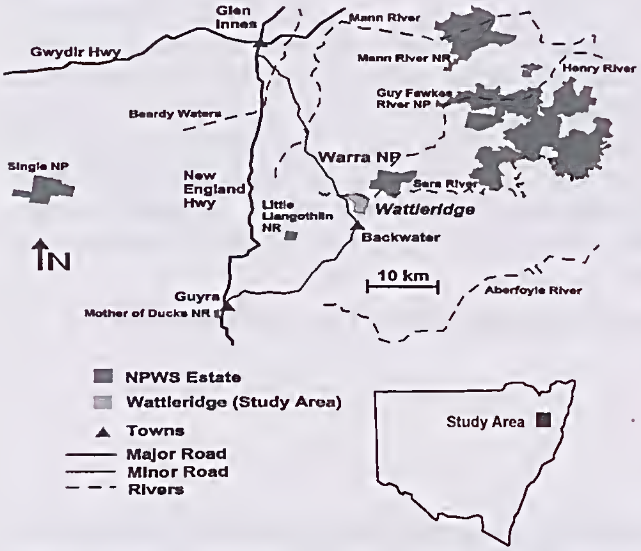

Fig. 1. Locality of Warra NP and *Wattleridge*.

Much of Warra NP is on a high central plateau dominated by Nightcap Mountain in the north at 1372 m and Crown Mountain to the south at 1360 m. Most of the topography is gentle and undulating. Much of the central plateau area is dominated by extensive areas of exposed sheet granite, interspersed with swampy areas. A steep fall occurs on the southern flanks of Crown Mountain, dropping almost 300 m in a kilometre; the northern slopes of the central plateau fall more gradually. The southern flanks of Crown Mountain and Nightcap Mountain are often boulder strewn. The lowest point is in the southeast, around 980 m altitude.

Wattleridge has very similar landscape features to Warra. It is also dominated by a high ridge which runs along the eastern boundary and then extends west following the Sara River. Much of this high ridge is of sheet granite, or is strewn with large boulders. Flatter areas, which have been selectively cleared, run along the western and southern boundaries. Altitude within *Wattleridge* ranges from 1160 m to 1340 m.

Geology

Warra NP is situated within the Central Block (Gilligan & Brownlow 1987) of the southern New England Orogen, west of the Dyamberin Block and the N-S trending Wongwibinda and Demon Faults. There is only one rock type within its boundaries — the Oban River Leucomonzogranite, an I-type leucocratic granite. This unit is comprised of very coarse-grained, leucocratic, equigranular, biotite granite with phases of fine to very fine-grained saccharoidal, pink, equigranular microleucogranite, the finer grained microleucogranite forming a carapace overlying the coarser grained rock (Gilligan et al. 1992).

Landuse and fire history

Mining occurred throughout the region and was particularly prevalent within the Backwater area and especially along the Sara River and its tributaries. Much of the mining was alluvial for tin. Even today sapphires are still worked in the area.

Wildfires are a common feature of this area. High intensity wildfires burnt most of Warra NP in 1988, 1994 and 2001 though *Wattleridge* was not burnt by these fires. When Warra was managed by NSW State Forests, prescribed fire intervals were 3–5 years for plateau areas, 4–7 years for gorge country and more than 10 years for wetter areas at higher altitudes, though how diligently these regimes were adhered to, is not known. Grazing permits existed within Warra at various times while under State Forest management, and though most leases were only lightly grazed, burning to create 'green pick' for cattle, was an integral part of grazing practice.

On much of the better grazing areas, on the more open and less rugged plateau areas, leaseholders probably kept low intensity fire frequency close to every three years.

Wattleridge has always been under private ownership and has been used as a grazing property with sheep, cattle and goats, up to the present. For much of the last 20 years the property has been dually managed as a working grazing property and farmstay. A majority of the property is uncleared, and due to its rugged nature, many areas were not, or at least little, grazed. These uncleared natural areas have been managed informally for conservation for the last thirty years as an attraction for ecotourists, and now more formally as an Indigenous Protected Area.

Previous investigations

In the 1920s and 1930s, the Reverend E.N. McKie, a schoolteacher at Backwater, investigated the flora of the region and a significant number of new species were described (usually in conjunction with W.F. Blakely, a botanist at the National Herbarium of NSW) based on his collections, particularly from areas such as Mushroom Rock (Pheasant Mountain), on the boundary of *Wattleridge*. Investigations into the flora were continued by John Williams of the

University of New England with many field schools taken to Backwater between 1960 and 1990. Williams (1991) produced a preliminary checklist of plants found on *Wattleridge*. Greg Roberts completed a masters preliminary thesis on the vegetation on granite on the Northern Tablelands and North Western Slopes, using Backwater as one of the main study sites (Roberts 1983). Binns (1992) recorded five vegetation survey sites within Warra for a comprehensive assessment of the vegetation under the management of the Glen Innes State Forests. Hunter (1992) described the vegetation and placed belt transects on *Wattleridge* in an investigation of sympatrically growing *Brachyloma* species. Hunter (1999) recorded 46 vegetation survey sites within the Backwater area, all within Warra NP or on *Wattleridge*, for investigation into the biogeography of the granitic outcrop flora of the New England. Benson and Ashby (2000) recorded seven floristic survey sites within Warra NP and a number of others in the Backwater area during vegetation mapping of the Guyra 1: 100 000 map sheet.

Targeted surveys for rare and threatened plants species have also been conducted within Warra NP. Quinn et al. (1995) surveyed for threatened species as did Richards (1996). Hunter (1996) also conducted surveys and produced a draft recovery plan for the threatened species within the Backwater area.

Methods

Existing information was compiled from previous surveys of the two areas including: Williams (1991), Binns (1992), Hunter (1992), Hunter (1996), Richards (1996), Hunter (1999), Hunter (2001) and Hunter (2003d). Records from Hunter (1999) were taken from surveys of granite outcrops only and were of a nested plot design and an area of 33 × 33 m (see Hunter & Clarke 1998), those of Hunter (1992) were of 120 m x 10 m belt transects, while all other sites were surveyed using the Braun-Blanquet (1982) six point cover abundance scale within a 20 x 50 m plot. An additional 50, 20 x 20 m, sites were recorded in Warra NP over 5 days in January of 2001 (Hunter 2001). A further 15, 20 x 20 m, sites were recorded within *Wattleridge* over 2 days in August 2003 (Hunter 2003) to assess and align vegetation assemblages with those already described for Warra NP by Hunter (2001). In total, data from 157 sites, each 20 x 20 m, 20 x 50 m or 33 x 33 m, were collated along with existing information from all other previous investigations in the region.

This paper presents a summary of all the investigations carried out for these two areas. As the aims and methods of the many of the previous investigations varied greatly only one subset of information was used to formally describe the vegetated systems within the two study areas. The fifty sites from Hunter (2001) are the only ones used in the analysis presented here. These fifty sites were placed using a stratified random method within Warra NP; strata included altitude and physiography. The communities defined from this analysis were extrapolated based on the additional information from the 107 other sites to all areas under investigation. Rock outcrops sites were not part of the stratification of Hunter (2001) as these areas were deemed to have been sufficiently described by Hunter (1999); thus although outcrop communities are mapped and described here, they are based on the work of Hunter & Clarke (1998). In addition to surveying outcrop vegetation, Hunter (1999) placed some sites within the surrounding matrix, and analysed their relationships with communities in the nearby matrix (Hunter 2002c).

Good quality specimens weres retained as vouchers by the New England Tablelands Region, National Parks and Wildlife Service, and by the NCW Beadle Herbarium of the University of New England (NE). Nomenclature follows that of Harden (1993–2002) except where recent changes have been made.

Analysis and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a, b). For final presentation of results all species (including exotics) and their cover abundance scores were used. Analysis was performed using Kulczynski association measure, which is recommended for ecological applications (Belbin 1995a, b) along with flexible Unweighted Pair Group arithmetic Averaging (UPGMA) and the default PATN settings.

Delineation of community boundaries was based on the location of sites and their position within the multivariate analysis, air photograph interpretation, substrate and ground truthing. The vegetation maps are based on a 1: 25 000 scale. Structural names follow Specht et al. (1995) and are based on the most consistent uppermost stratum.

Results

Vegetation communities

The vegetation communities described for Warra NP and *Wattleridge* are broadly similar to many communities found throughout the central parts of the Northern Tablelands from Ebor to the Queensland border (Binns 1992; Hunter & Clarke 1998; Hunter & Alexander 1999; Hunter et al. 1999; Benwell 2000; Hunter 2000b; Hunter & Sheringham 2002; Hunter 2004bc; Hunter 2004d). Most communities are of a woodland or forest structure, and these may have one or two shrub layers, or be primarily grassy. Heaths occur on rock outcrops, and in areas of impeded drainage where *Sphagnum* may be present.

From the analyses, nine vegetation communities are recognized at the dissimilarity measure of 0.8 in the dendrogram (Fig. 2) which shows three major groups: Communities 1–4 are primarily in waterlogged or periodically waterlogged areas; Communities 5–6 are woodlands to forest with a very shrubby understorey; and Communities 7–9 are primarily taller forests with a grassy understorey.

Within the following summary descriptions extreme values are given in brackets. Exotic species are not listed below but are included within Appendix 1. In all 549 taxa were found from 94 families and 290 genera, of which 495 taxa were recorded in Warra NP and 480 were recorded at *Wattleridge*. Species from each layer are listed in order of decreasing importance (cover x frequency). The number of hectares given is based only on what is formally reserved within Warra NP.

Community 1: *Leptospermum novae-angliae* (New England Tea-tree) — *Bursaria spinosa* (Blackthorn) — *Callitris oblonga* (Tasmanian Cypress)

Distribution: on skeletal soil on exposed granite rocks associated with river banks, with loamy sand and grey-brown soils. This community occurs in both study areas, where it is restricted to the rockier parts of the Sara River.

Structure: riparian scrub and heath, sometimes a low open woodland. Tree layer: 10–15 m tall; 10–15% cover. Tall shrub layer sometimes absent: 8–12 m tall; c. 20%. Low shrub layer: 1–3 m tall; 40–60% cover. Herb layer: > 1 m tall; c. 30% (Fig. 5).

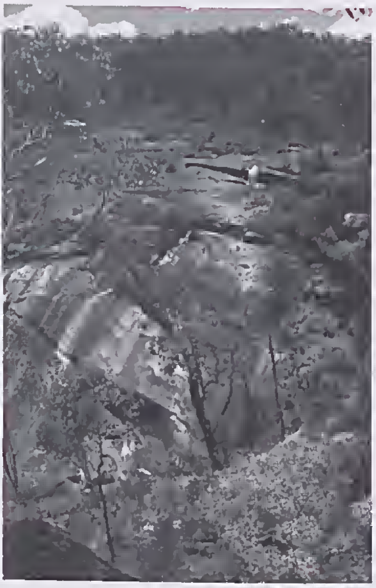

Fig. 5. Community 1: *Leptospermum novae-angliae – Bursaria spinosa* shrubland & heath along the Sara River.

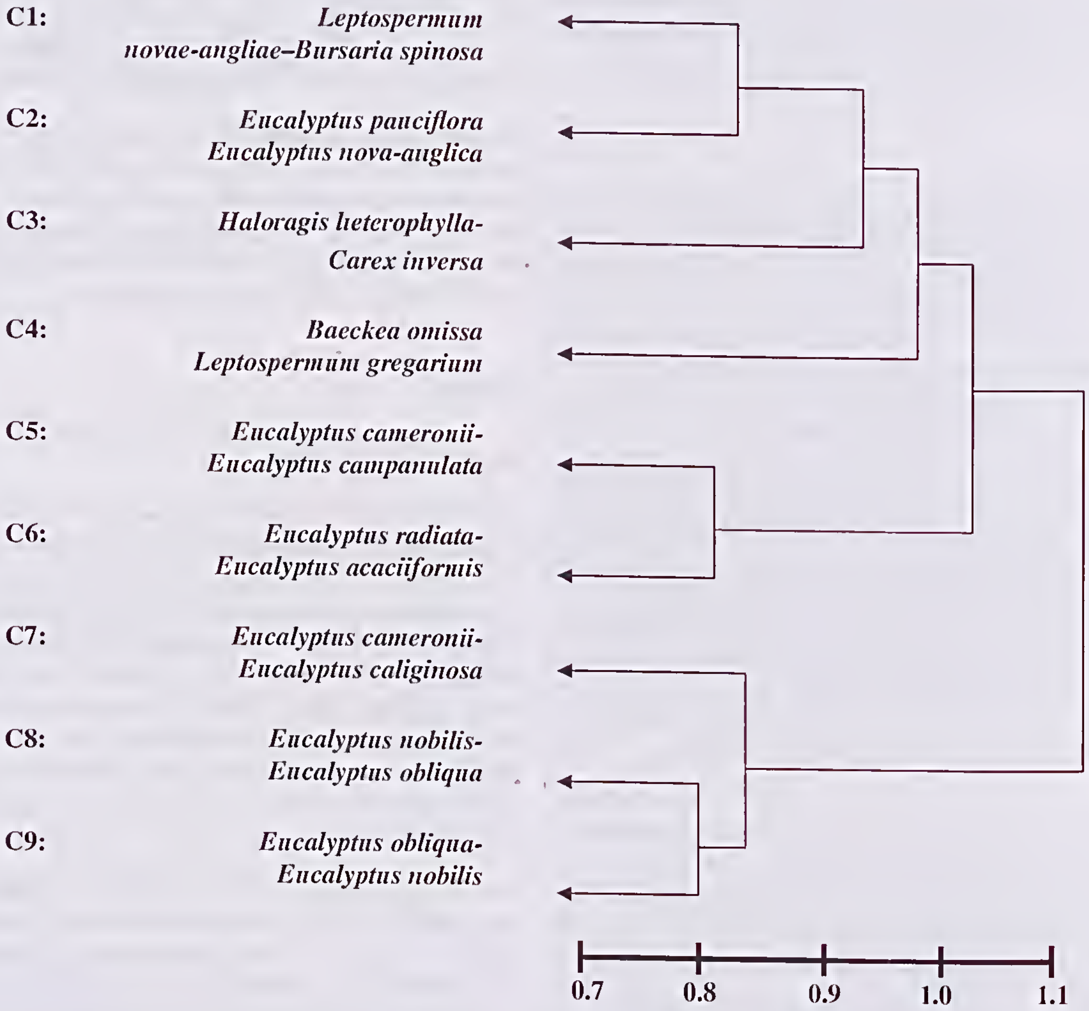

Fig. 2. Summary dendrogram of non-outcrop dataset of sites using Kulczynski association and flexible UPGMA fusion strategy. Communities are defined at a dissociation of 0.8.

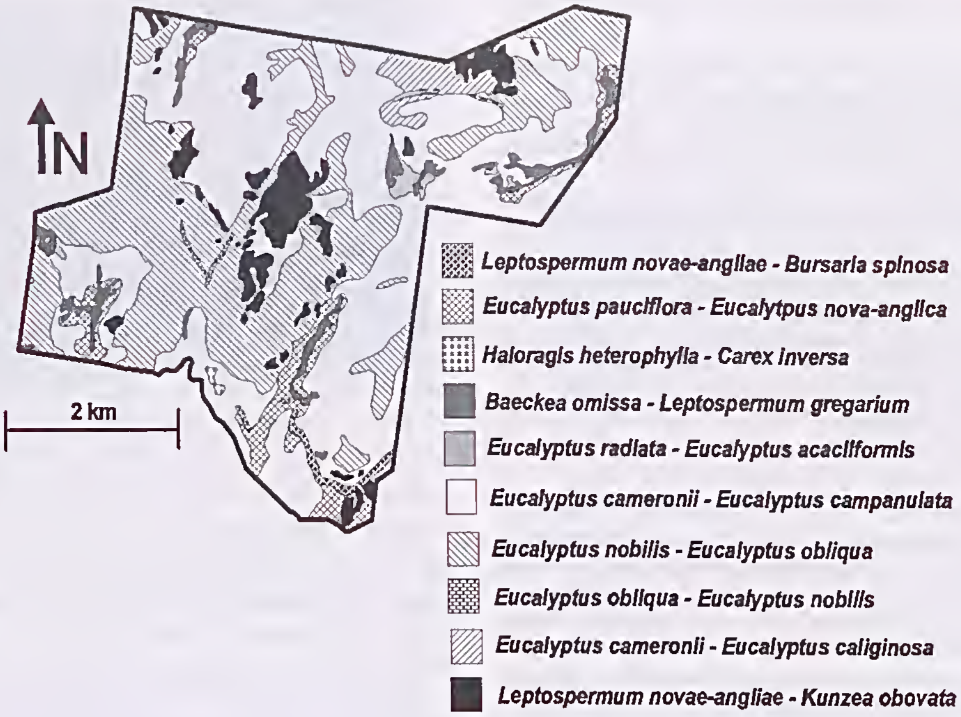
N
2 km
Leptospermum novae-angliae - Bursaria spinosa
Eucalyptus pauciflora - Eucalytpus nova-anglica
Haloragis heterophylla - Carex inversa
Baeckea omissa - Leptospermum gregarium
Eucalyptus radiata - Eucalyptus acaciiformis
Eucalyptus cameronii - Eucalyptus campanulata
Eucalyptus nobilis - Eucalyptus obliqua
Eucalyptus obliqua - Eucalyptus nobilis
Eucalyptus cameronii - Eucalyptus caliginosa
Leptospermum novae-angliae - Kunzea obovata

Fig. 3. Map of vegetation communities at Warra National Park.

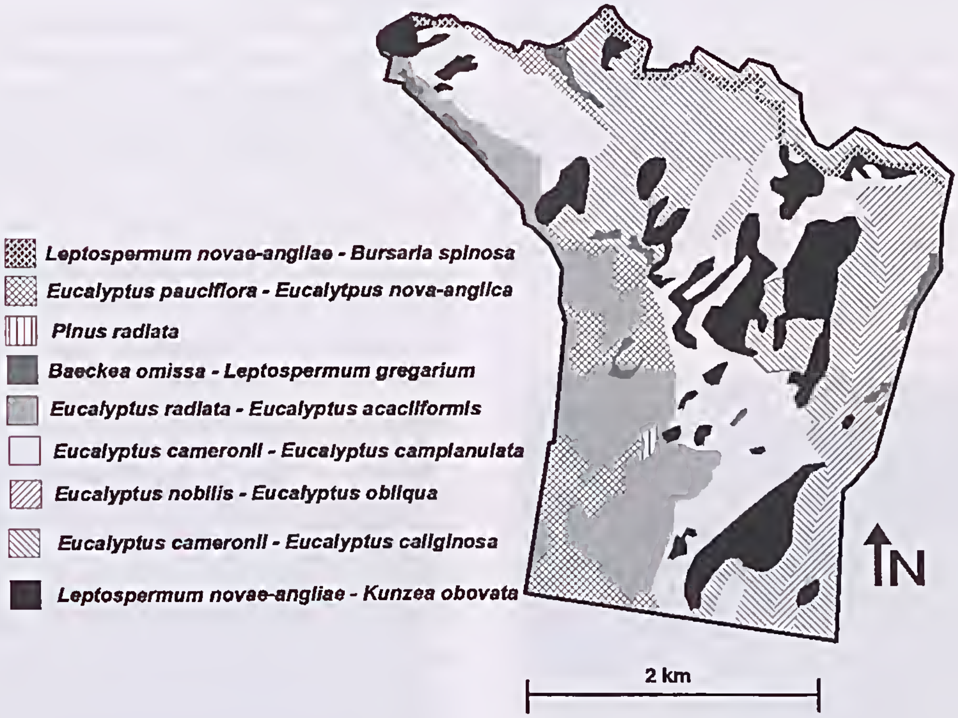
Leptospermum novae-angliae - Bursaria spinosa
Eucalyptus pauciflora - Eucalytpus nova-anglica
Pinus radiata
Baeckea omissa - Leptospermum gregarium
Eucalyptus radiata - Eucalyptus acaciiformis
Eucalyptus cameronii - Eucalyptus camplanulata
Eucalyptus nobilis - Eucalyptus obliqua
Eucalyptus cameronii - Eucalyptus caliginosa
Leptospermum novae-angliae - Kunzea obovata
N
2 km

Fig. 4. Map of vegetation communities at Wattleridge.

Trees: *Eucalyptus dalrympleana* subsp. *heptantha*, *Eucalyptus caliginosa*.

Shrubs: *Leptospermum novae-angliae*, *Bursaria spinosa*, *Acacia fimbriata*, *Callitris oblonga* subsp. *parva*, *Pomaderris nitidula*, *Logania albiflora*, *Leptospermum polygalifolium* subsp. *transmontanum*, *Leptospermum brevipes*, *Leucopogon biflorus*, *Kunzea obovata*, *Correa reflexa*, *Brachyloma saxicola*.

Climbers & trailers: *Rubus parviflorus*, *Persicaria hydropiper*.

Ground cover: *Wahlenbergia communis*, *Dichelachne crinita*, *Adiantum aethiopicum*, *Poa sieberiana*, *Entolasia stricta*, *Vittadinia dissecta*, *Tripogon loliiformis*, *Thonandia longifolia*, *Themeda australis*, *Sporobolus creber*, *Schoenus apogon*, *Poa labillardieri*, *Plectranthus graveolens*, *Opercularia diphylla*, *Fimbristylis dichotoma*, *Euchiton sphaericus*, *Dichelachne micrantha*, *Dichelachne inaequiglumis*, *Dianella caerulea*, *Cymbopogon refractus*, *Cheilanthes sieberi*, *Calandrinia* sp. A, *Austrodanthonia racemosa* subsp. *racemosa*, *Austrodanthonia monticola*, *Aristida ramosa*.

Variability: by its nature this community has a large edge to area ratio, and even common dominants may be absent due to the variability in substrate and depth of soil and flooding events, thus giving a variable structure. The riverbanks include extensive sheet granite and boulder strewn areas and many species are shared with community 10 where exposed granite platforms are larger and less exposed to riparian influences. Where alluvium is deeper and drainage is impeded, similarities with community 4 are apparent.

Notes: the floristics are probably reliant on a constant cycle of disturbance by flooding and fire. Benson and Ashby (2000) consider this community type to be endangered locally and at least vulnerable within NSW. They also consider the community to be poorly conserved locally. Based on published floristic analyses this community type does not appear to be represented in other reserves and no synonymous assemblages are described. Hence, it is likely that this grouping of taxa is unique to the Tablelands. [6 sites; 15 ha].

Community 2: *Eucalyptus pauciflora* (Snow Gum) — *Eucalyptus nova-anglica* (New England Peppermint)

Distribution: found primarily on lower slopes and open depressions with moist soils. Soils are primarily loamy sand, but also sandy, grey to yellow brown, shallow or deep.

Structure: woodlands. Tree layer: 15–20 m tall; 20–30% cover. Tall shrub layer sometimes absent: 2–6 m tall; 10–20% cover. Low shrub layer: 1–2 m tall; 20–60% cover. Herb layer: < 1 m tall; 50–80% cover (Fig. 6).

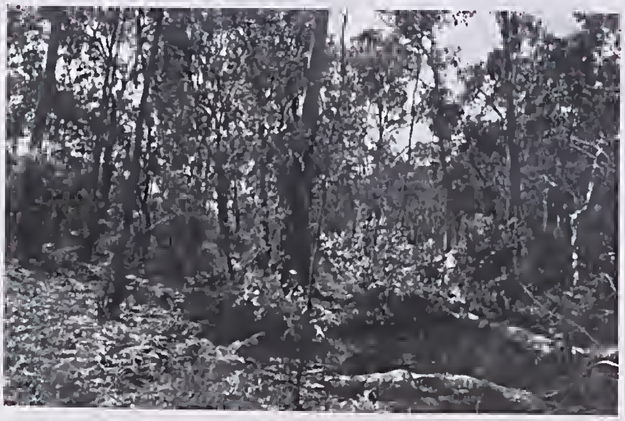

Fig. 6. Community 2: *Eucalyptus pauciflora – Eucalyptus nova-anglica* woodland.

Trees: *Eucalyptus pauciflora*, *Banksia integrifolia*, *Eucalyptus nova-anglica*, *Eucalyptus dalrympleana* subsp. *heptantha*, *Eucalyptus viminalis*, *Eucalyptus camphora*, *Eucalyptus caliginosa*.

Shrubs: *Persoonia procumbens*, *Leptospermum polygalifolium* subsp. *transmontanum*, *Aotus subglauca* var. *subglauca*, *Grevillea scortechinii* var. *sarmentosa*, *Brachyloma daphnoides* subsp. *glabrum*, *Monotoca scoparia*, *Melichrus procumbens*, *Dillwynia retorta*, *Bursaria spinosa*, *Mirbelia confertiflora*, *Hovea heterophylla*, *Dillwynia sieberi*, *Bossiaea neo-anglica*, *Petrophile canescens*, *Logania albiflora*, *Hibbertia riparia*, *Grevillea juniperina* subsp. *allojohnsonii*, *Dodonaea viscosa*, *Choretrum pauciflorum*, *Bossiaea scortechinii*, *Baeckea omissa*.

Climbers & trailers: *Glycine tabacina*, *Rubus parvifolius*, *Glycine clandestina*.

Ground cover: *Pteridium esculentum*, *Themeda australis*, *Lomandra longifolia*, *Brachyscome nova-anglica*, *Dichelachne micrantha*, *Stylidium graminifolium*, *Imperata cylindrica*, *Dichelachne inaequiglumis*, *Poa sieberiana*, *Lomandra multiflora*, *Microlaena stipoides*, *Goodenia hederacea*, *Austrodanthonia racemosa* var. *racemosa*, *Adiantum aethiopicum*, *Wahlenbergia communis*, *Sorghum leiocladum*, *Poranthera microphylla*, *Helichrysum scorpioides*, *Aristida ramosa*, *Trachymene incisa*, *Stackhousia viminea*, *Opercularia diphylla*, *Gonocarpus tetragynus*, *Entolasia stricta*, *Echinopogon caespitosus*, *Dichondra repens*, *Dichelachne crinita*, *Derwentia arcuata*, *Calandrinia* sp. A, *Austrostipa rudis* subsp. *nervosa*.

Variability: the height and cover of the tree layer is variable and probably dependent on how exposed the site is to frost. Some localities have an open tree layer that is short to 15 m tall and dominated mainly by *Eucalyptus pauciflora* and *Eucalyptus nova-anglica*, however in less exposed situations, particularly if slightly elevated, *Eucalyptus caliginosa* may become more prominent with an increase in height and density of the trees. This community intergrades with communities 4 and 6, as drainage becomes more impeded, or Community 7 where sites are more elevated.

Notes: this community is associated with low-lying areas, affected by frosts at higher altitudes. Within the study areas it is found associated with low lying-sites adjacent to the Sara River, and also in open frost hollows in broader gullies. Broadly similar associations may occur as far north as the Queensland border and as far south as New England and Coolah Tops National Parks. However, communities most closely allied to this assemblage are probably restricted to sporadic localities in the Guyra area, and potentially as far north as Butterleaf and as far south as Cathedral Rock National Park. Benson and Ashby (2000) considered this assemblage to be one of the most endangered communities both within the local area and within NSW. [7 sites; 100 ha].

Community 3: *Haloragis heterophylla* (Variable Raspwort) — *Carex inversa* (Sedge)

Distribution: previously cleared land on a lower slope associated with the Sara River.

Structure: herbfield. Herb layer: < 50 cm tall; 100% cover (Fig. 7).

Trees: none apparent.

Shrubs: none apparent.

Climbers & trailers: *Rubus parviflorus*.

Ground cover: *Haloragis heterophylla*, *Carex inversa*, *Agrostis avenacea*, *Thonandia longifolia*, *Scleranthus biflorus*, *Rumex brownii*, *Pteridium esculentum*, *Persicaria decipiens*, *Juncus vaginatus*, *Eragrostis elongata*, *Epilobium billardierianum*, *Dichondra repens*, *Austrodanthonia racemosa* var. *racemosa*, *Alternanthera* sp. A, *Phyllanthus virgatus*, *Linum marginale*, *Austrodanthonia induta*.

Variability: an assemblage that has only been sampled by one quadrat, hence no variability noted.

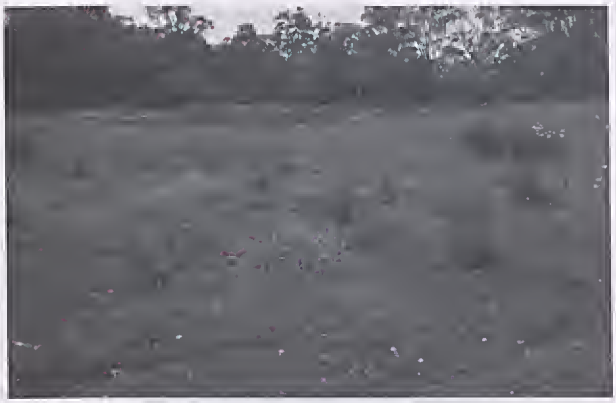

Fig. 7. Community 3: *Haloragis heterophylla – Carex inversa herbfield*

Notes: despite being a derived assemblage due to past clearing some of the components of this open herbfield show affinities to other open grasslands and herbfields from Guy Fawkes River NP and New England NP. [1 site; 3 ha].

Community 4: *Baeckea omissa* (Baeckea) — *Leptospermum gregarium* (Swamp Tea-tree)

Distribution: patchily distributed in open or closed depressions associated with areas of impeded drainage along creeks. Soils are damp to waterlogged, usually loamy sand, but also loam to clay, grey-brown to black and deep.

Structure: mainly heaths, but also low open woodlands and mallee. Tree layer sometimes absent: (3–) 8–15 (–30) m tall; 10–30% cover. Tall shrub layer often absent: 2–6 m tall; c. 30% cover. Low shrub layer usually absent: 1–2 m tall; 30–80% Herb layer: < 1 m tall; 40–100% cover (Fig. 8).

Trees: *Eucalyptus camphora* subsp. *relicta, Eucalyptus pauciflora, Eucalyptus dalrympleana* subsp. *heptantha, Banksia integrifolia, Eucalyptus acaciiformis, Eucalyptus nova-anglica, Eucalyptus caliginosa, Eucalyptus nobilis.*

Shrubs: *Baeckea omissa, Leptospermum gregarium, Epacris microphylla, Callistemon pityoides, Banksia cunninghamii, Hakea microcarpa, Lomatia fraseri, Callistemon pallidus, Hakea eriantha, Scaevola ramosissima, Pimelea linifolia, Hibbertia riparia, Aotus subglauca* var. *subglauca, Petrophile canescens, Monotoca scoparia, Acacia filicifolia.*

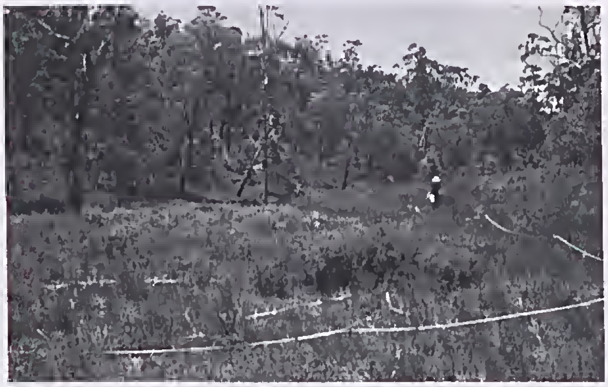

Fig. 8. Community 4. *Baeckea omissa – Leptospermum gregarium wet heath.*

Climbers & trailers: *Rubus parvifolius, Glycine* sp. A, *Glycine clandestina.*

Ground cover: *Baloskion fimbriatum, Goodenia bellidifolia, Lepidosperma limicola, Geranium solanderi* var. *grande, Lomandra longifolia, Schoenus apogon, Gonocarpus micranthus, Helichrysum scorpioides, Viola hederacea, Pteridium esculentum, Patersonia fragilis, Lepyrodia anarthria, Entolasia stricta, Dichelachne inaequiglumis, Patersonia glabrata, Juncus vaginatus, Isachne globosa, Hypericum gramineum, Haloragis heterophylla, Goodenia hederacea, Xyris complanata, Utricularia dichotoma, Themeda australis, Stylidium graminifolium, Scirpus polystachyus, Lepidosperma gunnii, Echinopogon caespitosus, Drosera burmannii, Craspedia variabilis, Carex lobolepis, Baloskion stenocoleum, Austrofestuca eriopoda, Xyris operculata, Thelionema caespitosum, Poa sieberiana, Imperata cylindrica, Epilobium gunnianum, Austrodanthonia racemosa* var. *racemosa, Thelionema grande, Poranthera microphylla, Lythrum salicaria, Lepyrodia leptocaulis, Hydrocotyle geraniifolia, Dichondra repens, Cyperus sphaeroideus, Carex inversa.*

Variability: such assemblages are usually isolated, small and generally of limited distribution, and many associated species are variable in their presence. Often zonation occurs into grass and cyperoid-dominated areas, along with situations with a strong shrub component. Such internal variability is due to depth and duration of waterlogging. In a very few localities *Sphagnum* bogs have developed.

Notes: few completely comparable examples of this assemblage can be found within the literature. Similar associations are restricted to higher altitudes on the Tablelands particularly along the eastern margin of the Great Divide. Communities such as these are usually highly divergent across relatively small distances, and as such most occurrences are unique. Benson and Ashby (2000) considered this type of assemblage to be poorly-conserved locally, but moderately conserved within NSW. Similar small isolated occurrences are likely to within most reserves on the escarpment and associated Tablelands areas from the Queensland border to Barrington and Coolah Tops. Broadly similar assemblages are known to be reserved within Gibraltar Range NP, New England NP, Basket Swamp NP, Boonoo Boonoo NP, Bald Rock NP, Girraween NP, Demon NR, Cathedral Rocks NP, Mann River NP, Coolah Tops NP, western Washpool Western NP, Werrikimbe NP, Capoompeta NP and Butterleaf NP (Hunter et al. 1999; Hunter 2000b; Whinam & Chilcott 2002; Hunter 2004bc; Hunter 2005). Despite the above, areas which include *Sphagnum* should be considered endangered on the Tablelands as only a few occurrences survive in good condition. It is likely that only a few hectares of these bogs occur across the whole Tablelands (Whinam & Chilcott 2002). [8 sites; 69 ha].

Community 5: *Eucalyptus cameronii* (Diehard Stringybark) — *Eucalyptus caliginosa* (Broad-leaved Stringybark) — *Eucalyptus campanulata* (Eastern New England Blackbutt)

Distribution: within Warra NP this community is restricted to Nightcap Mountain in the northeastern corner, and in the upper reaches of Comptons Gully. It is more widespread within *Wattleridge* where it is found in a variety of landscape situations, from upper slopes to open depressions and lower slopes. Soils are usually well drained but can be damp to moist and usually shallow. Soils texture and colour are generally loamy sand and dark-brown, or yellow-brown to black.

Structure: open forests. Tree layer: 20–30 m tall; 30–35% cover. Low shrub layer: 1–2 m tall; 20–80% cover. Herb layer: < 1 m tall; 60–80% cover (Fig. 9).

Trees: *Eucalyptus cameronii, Eucalyptus caliginosa, Eucalyptus campanulata, Eucalyptus radiata* subsp. *sejuncta.*

Shrubs: *Dillwynia phylicoides, Lomatia silaifolia, Bossiaea neo-anglica, Banksia cunninghamii, Monotoca scoparia, Leucopogon lanceolatus, Hovea pedunculata, Hibbertia* sp. aff. *obtusifolia,*

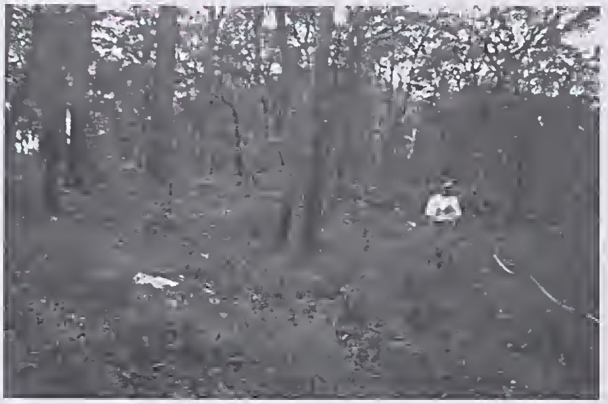

Fig. 9. Community 5: *Eucalyptus cameronii – Eucalyptus campanulata* Forest.

Pomaderris lanigera, Acacia ulicifolia, Acocia myrtifolia, Pultenaea linophylla, Platysace lanceolata, Hakea eriantha, Acacia mitchellii, Petrophile canescens, Melichrus procumbens, Grevillea scortechinii, Boronia algida, Acacia buxifolia, Prostanthera scutellarioides, Polyscias sambucifolia, Pimelea linifolia, Maytenus silvestris, Dodonaea triquetra, Bossiaea scortechinii .

Climbers & trailers: *Billardiera scandens, Smilax australis, Hardenbergia violacea.*

Ground cover: *Platysace ericoides, Goodenia hederacea, Austrodanthonia racemosa* var. *racemosa, Pteridium esculentum, Pomax umbellata, Lomandra longifolia, Lepidosperma laterale, Entolasia stricta, Stylidium graminifolium, Poa sieberiana, Patersonia glabrata, Gonocarpus tetragynus, Poa queenslandica, Goodenia bellidifolia, Schoenus melanostachys, Lomandra multiflora, Lindsaea linearis, Dianella caerulea, Calochlaena dubia, Stackhousia monogyna, Patersonia sericea, Microlaena stipoides, Gonocarpus oreophilus, Dianella revoluta.*

Variability: the structure of this community is constant, despite the often changing understorey floristics. These understorey changes are probably due to past fires with varying intensities, promoting some species over others. It is likely that, with a longer absence of fire, the understorey will become denser and taller and form a thick almost impenetrable layer.

Notes: no truly comparable assemblages were found within the literature. Broadly though, it is synonymous with a number of assemblages along the eastern escarpment on coarse granitic soils from Cathedral Rock NP to the Queensland border. This assemblage intergrades with Community 6 particularly where drainage is intermediate and with Community 7. [11 sites; 48 ha].

Community 6: *Eucalyptus radiata* subsp. *sejuncta* (Narrow-leaved Peppermint) — *Eucalyptus acaciiformis* (Wattle-leaved Peppermint)

Distribution: low-lying flats and open depressions particularly around the margins of swamps and wet heaths. Soils are moist to damp, loamy or sandy loam, black to dark brown and deep.

Structure: woodlands. Tree layer: 15–20 m tall; c. 20% cover. Tall shrub layer sometimes absent: 2–4 m tall; 10% cover. Low shrub layer: 1–2 m tall; 70–80% cover. Herb layer: < 1 m tall; 20–80% cover (Fig. 10).

Trees: *Eucalyptus radiata* subsp. *sejuncta, Eucalyptus acaciiformis, Eucalyptus campanulata.*

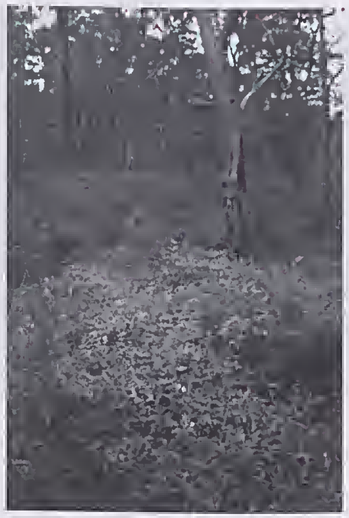

Fig. 10. Community 6: *Eucalyptus radiata* subsp. *sejuncta – Eucalyptus acaciiformis* woodlands.

Shrubs: *Grevillea scortechinii* subsp. *sarmentosa, Leptospermum brevipes, Banksia cunninghamii, Aotus subglauca* var. *subglauca, Petrophile canescens, Epacris microphylla, Dillwynia phylicoides, Baeckea omissa, Mirbelia pungens, Leptospermum novae-angliae, Callistemon pallidus, Acacia buxifolia, Hibbertia acicularis, Xanthorrhoea glauca, Persoonia procumbens, Lomatia silaifolia, Monotoca scoparia, Acacia ulicifolia.*

Climbers & trailers: *Billardiera scandens.*

Ground cover: *Goodenia bellidifolia, Baloskion fimbriatum, Schoenus melanostachys, Goodenia hederacea, Entolasia stricta, Austrodanthonia racemosa* var. *racemosa, Stylidium graminifolium, Lomandra longifolia, Gonocarpus tetragynus, Gonocarpus micranthus, Dianella revoluta, Austrodanthonia monticola, Pteridium esculentum, Poranthera microphylla, Poa sieberiana, Patersonia sericea, Microlaena stipoides, Juncus vaginatus, Wahlenbergia ceracea, Thysanotus tuberosus, Patersonia fragilis, Lindsaea linearis, Lepyrodia anarthria, Lepidosperma limicola, Lagenifera stipitata, Imperata cylindrica, Hypericum gramineum, Gahnia aspera, Dichelachne micrantha.*

Variability: the major changes associated with this assemblage are the prominence or absence of shrubs in the understorey. Where this community occurs on sandier soils it usually boasts a dense heathy understorey, as in Warra NP, but as soils become heavier the heath is replaced by herbs and grasses, as at *Wattleridge.*

Notes: this community often occurs in areas that may be periodically inundated. Beadle (1981) states that *Eucalyptus radiata* is commonly associated with *Eucalyptus acaciiformis* where rainfall is generally greater than 1000 mm annually, and where soils are of low fertility and especially where drainage is impeded. It is therefore likely that this assemblage is restricted to low-lying areas with impeded drainage, but not areas that are waterlogged. This community naturally intergrades with community 4 where waterlogging is more prolonged, and with community 2 where drainage is better, which is not surprising, as *Eucalyptus pauciflora* replaces *Eucalyptus acaciiformis* where soils are less prone to waterlogging. Some intergradations occur with community 5 which commonly borders this assemblage. Benson and Ashby (2000) consider this community to be vulnerable and poorly conserved across both locally and across NSW. [4 sites; 14 ha].

Community 7: *Eucalyptus cameronii* (Diehard Stringybark) — *Eucalyptus caliginosa* (Broad-leaved Stringybark)

Distribution: sampled primarily from lower slopes, but also on middle to upper slopes. Soils are well-drained to moist, loamy sand to sandy loam, predominantly grey-brown in colour but also yellow-brown, light-brown to dark-brown with a variable depth.

Structure: mainly woodlands to open forests, occasionally tall open forests. Tree layer: 20–40 m tall; 30–40% cover. Tall shrub layer sometimes absent: (3–) 4–8 (–15) m tall; (10–) 20–40 (–70)% cover. Low shrub layer usually not present: 1–2 m tall; (10–) 20–60% cover. Herb layer: < 1 m tall; 60–90% cover (Fig. 11).

Trees: *Eucalyptus cameronii, Eucalyptus caliginosa, Banksia integrifolia, Allocasuarina littoralis, Eucalyptus radiata* subsp. *sejuncta, Eucalyptus nobilis, Eucalyptus nova-anglica, Eucalyptus pauciflora, Eucalyptus dalrympleana* subsp. *heptantha, Eucalyptus viminalis, Eucalyptus obliqua, Eucalyptus stellulata.*

Shrubs: *Monotoca scoparia, Lomatia silaifolia, Bossiaea scortechinii, Acacia filicifolia, Leucopogon lanceolatus, Aotus subglauca* var. *subglauca, Polyscias sambucifolia, Melichrus urceolatus, Melichrus procumbens, Brachyloma daphnoides* subsp. *glabrum, Jacksonia scoparia, Dillwynia retorta, Platysace lanceolata, Persoonia cornifolia, Hibbertia* sp. aff. *obtusifolia, Hibbertia riparia, Bossiaea neo-anglica, Hovea heterophylla, Dodonaea triquetra, Banksia cunninghamii, Acacia fimbriata.*

Climbers & trailers: *Desmodium varians, Billardiera scandens, Hardenbergia violacea, Rubus parvifolius, Glycine* sp. A, *Glycine clandestina, Eustrephus latifolius.*

Ground cover: *Imperata cylindrica, Pteridium esculentum, Poa sieberiana, Entolasia stricta, Goodenia hederacea, Lomandra longifolia, Brachyscome nova-anglica, Echinopogon caespitosus, Austrodanthonia racemosa* subsp. *racemosa, Poranthera microphylla, Microlaena stipoides, Lepidosperma laterale, Gonocarpus tetragynus, Oxalis chnoodes, Dichelachne micrantha, Lomandra multiflora, Opercularia hispida, Wahlenbergia communis, Senecio diaschides, Dichelachne inaequiglumis, Viola betonicifolia, Helichrysum scorpioides, Stylidium gramineum, Pratia purpurascens, Patersonia sericea, Dianella revoluta, Austrostipa rudis* subsp. *nervosa, Poa queenslandica, Platysace ericoides, Hybanthus monopetalus, Podolepis neglecta, Lagenifera stipitata, Dianella caerulea, Hypericum gramineum, Dichondra repens, Craspedia variabilis, Lomandra filiformis, Gonocarpus teucrioides, Themeda australis, Pomax umbellata, Patersonia glabrata, Opercularia diphylla, Hydrocotyle peduncularis, Hydrocotyle laxiflora, Goodenia bellidifolia, Galium migrans, Gahnia aspera, Euchiton sphaericus, Austrodanthonia monticola.*

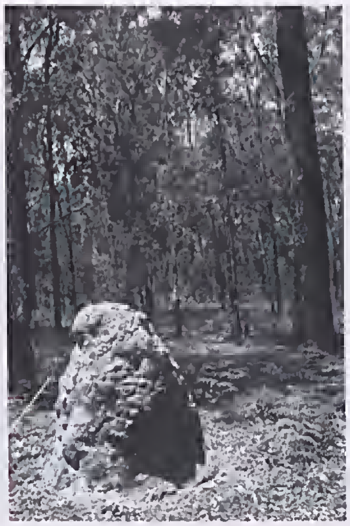

Fig. 11. Community 7: *Eucalyptus cameronii – Eucalyptus caliginosa* grassy open forest and woodland.

Variability: this is the most widespread community within the study area. A small and taller shrub layer are normally present, however, either may be missing and usually this is the lower shrub layer. This variability may in a large part by due to differences in fire regimes, both frequency and intensity. In some locations where only the upper shrub layer is present, it is rather sparse, and a dense layer of grasses may be prominent (particularly *Imperata cylindrica*).

Notes: this community occurs on more exposed sites than Community 8 with which it often intergrades. This assemblage also intergrades with the 'heathier' communities such as community 5 and 6. It is probably largely restricted to the Backwater area, however similar assemblages occur from as far south as New England NP to the Washpool Western Additions NP. [20 sites; 1058 ha].

Community 8: *Eucalyptus nobilis* (Manna Gum) — *Eucalyptus obliqua* (Messmate)

Distribution: usually on steeper slopes or in protected locations. Sampled on upper to lower slopes, primarily facing south or in protected localities. Floating boulders are common. Soils are generally moist to well drained, loamy sand, brown to dark-brown or grey, and shallow.

Structure: mainly open forest, but also tall open forest and occasionally woodland. Tree layer: (20–) 25–40 m tall; (20–) 30–40% cover. Tall shrub layer often absent: (3–) 5–12 m tall; (10–) 20–40% cover. Low shrub layer rarely present: 1–6 m tall; (10–) 20–60 (–90%) cover. Herb layer: < 1 m tall; 60–100% cover (Fig. 12).

Trees: *Eucalyptus caliginosa, Banksia integrifolia, Eucalyptus nobilis, Eucalyptus obliqua, Eucalyptus campanulata, Allocasuarina littoralis, Eucalyptus radiata* subsp. *sejuncta, Eucalyptus eugenioides, Eucalyptus stellulata, Eucalyptus cameronii.*

Shrubs: *Acacia filicifolia, Leucopogon lanceolatus, Bursaria spinosa, Lomatia silaifolia, Indigofera australis, Solanum campanulatum, Monotoca scoparia, Bossiaea neo-anglica.*

Climbers & trailers: *Rubus parvifolius, Desmodium varians, Glycine clandestina, Billardiera scandens, Hardenbergia violacea, Eustrephus latifolius, Smilax australis, Pyrrosia confluens, Glycine tabacina, Clematis glycinoides.*

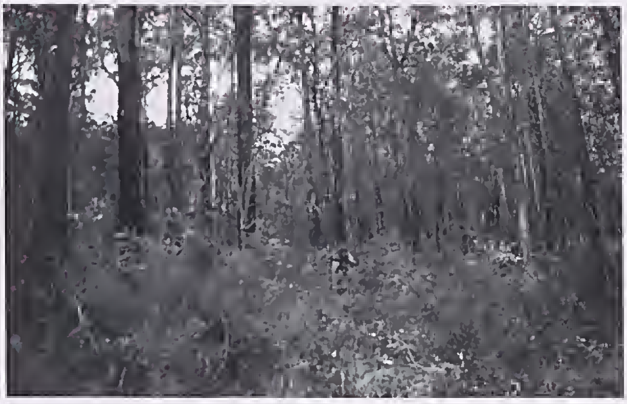

Fig. 12. Community 8: *Eucalyptus nobilis – Eucalyptus obliqua* open forest.

Ground cover: *Poa sieberiana, Pteridium esculentum, Imperata cylindrica, Dichondra repens, Microlaena stipoides, Senecio diaschides, Geranium solanderi* var. *solanderi, Lomandra longifolia, Hydrocotyle geraniifolia, Dichelachne inaequiglumis, Brachyscome nova-anglica, Austrodanthonia racemosa* var. *racemosa, Pratia purpurascens, Echinopogon caespitosus, Wahlenbergia communis, Poranthera microphylla, Galium migrans, Calochlaena dubia, Arthropodium milleflorum, Veronica calycina, Opercularia hispida, Lomandra filiformis, Hydrocotyle peduncularis, Dianella revoluta, Plantago varia, Lagenifera stipitata, Goodenia hederacea, Austrostipa rudis* var. *nervosa, Viola hederacea, Viola betonicifolia, Oxalis chnoodes, Echinopogon ovatus, Acaena novae-zelandiae, Senecio* sp. E, *Poa queenslandica, Entolasia stricta, Themeda australis, Stackhousia viminea, Ranunculus lappaceus, Podolepis neglecta, Platysace ericoides, Lomandra multiflora, Hydrocotyle laxiflora, Hybanthus monopetalus, Helichrysum scorpioides, Gonocarpus tetragynus, Euchiton sphaericus, Dichelachne micrantha, Adiantum aethiopicum.*

Variability: tree height can be dramatically variable forming low open forests to tall open forests. Shrubs are not a prominent component and a shrub layer is not always present. This may in part be due to variation in fire frequency and intensity, particularly in relation to the germination of cohorts of *Acacia*.

Notes: this community is the second most common assemblage within the study area. Similar assemblages occur in comparable situations in high altitude areas of Capoompeta and western Washpool NPs (Hunter 2000b; Hunter 2005), in high altitude areas around Scott Trig in Butterleaf NP (Binns 1992). Similar assemblages are sporadically distributed at high altitudes (1000–1400 m) between Guyra and Tenterfield, though broadly similar communities are also described for the Barrington Tops and New England NPs (Binns 1995; Clarke et al. 2000). Intergradation occurs with community 7 and the similar community 9. [15 sites; 705 ha].

Community 9: *Eucalyptus obliqua* (Messmate) — *Eucalyptus nobilis* (Manna Gum)

Distribution: only known from very protected sites in upper catchments around Crown and Nightcap Mountains. The soils are damp, loamy, dark brown and often shallow with many floating boulders.

Structure: tall open forest. Tree layer: 35–40 m tall; c. 30% cover. Tall shrub layer: 4–10 m tall; 20–30% cover. Low shrub layer not always present: 2–3 m tall; c.20% cover. Understorey layer: < 1 m tall; c. 90% cover (Fig. 13).

Trees: *Eucalyptus obliqua, Eucalyptus nobilis, Eucalyptus cameronii, Eucalyptus radiata* subsp. *sejuncta, Eucalyptus campanulata.*

Shrubs: *Coprosma quadrifida, Notelaea* sp. A, *Lomatia silaifolia, Solanum elegans, Solanum densevestitum, Rapanea variabilis, Acacia melanoxylon, Solanum campanulatum, Notelaea longifolia, Correa reflexa.*

Climbers & trailers: *Desmodium varians, Clematis aristata, Glycine clandestina, Geitonoplesium cymosum, Eustrephus latifolius, Rubus parvifolius, Smilax australis.*

Ground cover: *Calochlaena dubia, Blechnum cartilagineum, Polystichum fallax, Hydrocotyle geraniifolia, Dichondra repens, Pteridium esculentum, Pratia purpurascens, Microlaena stipoides, Dicksonia antarctica, Cyathea australis, Viola betonicifolia, Poa sieberiana, Doodia aspera, Carex inversa, Austrostipa rudis* var. *nervosa, Adiantum aethiopicum, Wahlenbergia communis, Viola hederacea, Veronica plebeia, Plantago varia, Lagenifera stipitata, Imperata cylindrica, Echinopogon caespitosus, Sigesbeckia australiensis, Senecio lautus, Senecio diaschides, Ranunculus lappaceus, Oxalis chnoodes, Oreomyrrhis eriopoda, Luzula flaccida, Gonocarpus teucrioides, Gonocarpus oreophilus, Geranium solanderi* var. *solanderi, Dianella revoluta, Carex inconitata, Xerochrysum bracteata, Blechnum wattsii, Austrostipa aristiglumis, Acianthus exsertus.*

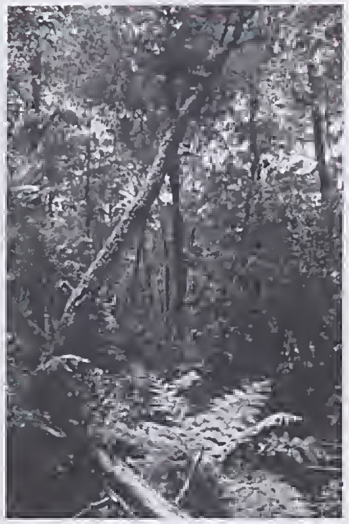

Fig. 13. Community 9: *Eucalyptus obliqua – Eucalyptus nobilis* tall open forest with a mesic understorey.

Variability: this community has many closed forest elements and their abundance and dominance vary according to time since the last fire incursion.

Notes: no directly comparable communities were found in the literature, however similar assemblages were described for the Washpool NP Western Additions. It is likely that under more favourable conditions, particularly a reduced fire regime, a mixed closed forest stand may develop in these localities. Intergradation occurs with community 8, or at times with community 7. [2 sites; 6 ha].

Community 10: *Leptospermum novae-angliae* (New England Tea-tree) — *Kunzea obovata* (Burgan) — *Brachyloma saxicola* (New England Daphne Heath)

Caveat: this community description is based on the work of Hunter (1999) presented in Hunter & Clarke (1998) and was not incorporated in the analyses of the other nine communities described here. Hunter (1999; 2002c) demonstrated by analysis that this assemblage was different from the other assemblages within the area.

Distribution: restricted to exposed granitic outcrops scattered throughout both study areas and particularly well-developed on extensive granite sheets between Crown and Nightcap Mountains.

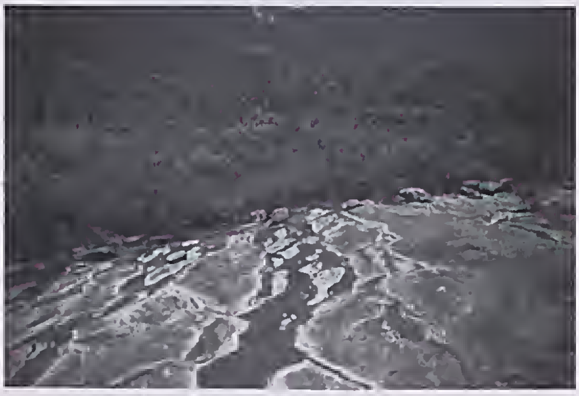

Fig. 14. Community 10: *Leptospermum novae-angliae – Kunzea obovata – Brachyloma saxicola* open scrub and heath, overtopped here by the mallee *Eucalyptus codonocarpa.*

Structure: structurally they are mainly closed heaths although the mallee *Eucalyptus codonocarpa* may be present forming shrubby open scrubs (mallee). Occasionally other trees species occur, such as *Eucalyptus campanulata, Euclyptus caliginosa, Eucalyptus acaciiformis* and *Euclyptus cameronii*, giving a shrubby low open woodland structure. In some instances *Leptospermum novae-angliae* at its tallest and densest will form closed scrub (Fig. 14).

Trees: *Eucalyptus codonocarpa, Eucalyptus caliginosa, Eucalyptus acaciiformis, Eucalyptus cameronii, Eucalyptus campanulata.*

Shrubs: *Leptospermum novae-angliae, Kunzea obovata, Leucopogon neoanglicus, Allocasuarina rigida* subsp. *rigida, Brachyloma saxicola, Mirbelia confertiflora, Calytrix tetragona, Prostanthera scutellarioides, Hovea pedunculata, Boronia anemonifolia* var. *variabilis, Acacia venulosa, Acacia ulicifolia, Hibbertia acicularis, Leucopogon microphyllus, Acacia falciformis, Dodonaea viscosa, Zieria cytisoides, Dillwynia phylicoides, Hakea laevipes* subsp. *graniticola, Persoonia cornifolia, Monotoca scoparia, Acacia viscidula.*

Climbers & trailers: *Muehlenbeckia costata, Billardiera scandens.*

Ground cover: *Lepidosperma gunnii, Gonocarpus teucrioides, Entolasia stricta, Platysace lanceolata, Schoenus apogon, Brachyscome stuartii, Lomandra longifolia, Monotaxis macrophylla, Gonocarpus micranthus, Galium sieberiana, Actinotus gibbonsii, Austrodanthonia monticola, Thelionema caespitosum, Cheilanthes sieberi, Stypandra glauca, Trachymene* sp. 'pilosa', *Dampiera stricta, Empodisma minus, Fimbristylis dichotoma, Dianella tasmanica, Bulbostylis densa, Trachymene incisa, Lepidosperma laterale, Aristida ramosa.*

Variability: highly stochastic. The small population sizes and the harsh environment afforded by rock outcrop habitats, necessarily means that even adjacent occurrences are likely to contain very different species assemblages (Hunter 2000a; Hunter 2002c; Hunter 2003bc; Hunter 2004a). Although a few species may be dominant in most situations they may be inexplicably missing, at least above-ground, from nearby sites. Disturbances such as fire can dramatically change the floristics and structure temporarily as a suite of short-lived disturbance ephemerals establish (Hunter 1995; Hunter 1998a; Hunter et al. 1998; Hunter 2003b).

Notes: this element is restricted to high altitude areas north and south-east of Glen Innes. The community as described here is Element 1 as given by Hunter & Clarke (1999) in their synopsis of the New England granitic outcrop communities. This element is further divided into three communities by Hunter & Clarke (1999) all of which occur in Warra NP and *Wattleridge*. This community type is also reserved at Butterleaf NP, and could be considered sufficiently reserved, but due to the stochasticity in floristics and small population sizes, further inclusions of this assemblage are important. Hunter (2000a; 2002c; 2003c) has shown that because of the nature of naturally fragmented ecosystems, any addition to the reserve network would significantly increase species richness and resilience of this assemblage. [39 sites; 129 ha].

Discussion

Warra NP and *Wattleridge* share a very similar composition of species and communities. Warra NP in general had a greater number of communities and species but this is not surprising as it is more than twice the size of *Wattleridge*. Within the 2689 ha investigated, 549 vascular plant taxa were found. Though this would likely increase with opportunistic sightings, the number found is high, especially considering that only around 8% of taxa were non-natives. The site richness (41 species per 0.04 ha) is similar to that recorded by Benson and Ashby (2000) in the same area.

Phytogeography

Floristic similarity is greatest overall with the floras further south, rather than those north or to the west. This is not surprising considering the number of species that appear to be disjunctions from taxa further south (e.g. *Acacia mitchellii*) or are taxa derived from species now occurring in more southern localities (e.g. *Eucalyptus camphora* subsp. *relicta*). Most communities showed affinities with others that are typical of those found along the higher parts of the eastern escarpment from Ebor to east of Tenterfield.

Although communities dominated by *Eucalyptus obliqua* and *Eucalyptus nobilis* (community 7 & 8) occur throughout the eastern side of the New England Tableland, the prominence of *Eucalyptus nobilis* drops considerably further north and is replaced generally by *Eucalyptus brunnea*. Communities similar to that of 7 and 8 are probably near their northern limits within the study area but are well developed locally.

The heathy/sedgelands (community 4) found within Warra are typical of those found at higher altitudes to the east. Whinam and Chilcott (2002) showed that the *Sphagnum* bogs at Warra NP were floristically grouped with others restricted to the eastern parts of the Northern Tablelands at altitudes above 1050 m. Though Whinam and Chilcott (2002) did not sample them, *Sphagnum* bogs do occur as far north as the Queensland border, such as at Demon NR (Hunter et al. 1999) and Basket Swamp NP (Hunter 2004b). However, those of Warra NP are the most northerly of those that have developed very deep and distinctive hummock and hollow systems, and are of great regional importance.

Conservation issues

Approximately 60% of the woody vegetation in the New England Bioregion has been cleared (Benson 1999) and within the local area more than 70% has probably been cleared (Benson & Ashby 2001).

Two communities identified by Benson and Ashby (2001) as endangered locally, and endangered or vulnerable within NSW, occur within Warra NP. These are the *Leptospermum novae-angliae – Bursaria spinosa*, and the *Eucalyptus pauciflora – Eucalyptus nova-anglica* communities. The *Eucalyptus radiata – Eucalyptus acaciiformis* community was considered to be vulnerable, locally and within NSW (Benson & Ashby 2001). Additionally it is suggested that *Eucalyptus obliqua – Eucalyptus nobilis* is vulnerable, at least locally, and that the *Sphagnum* component of the *Baeckea omissa – Leptospermum gregarium* community should be considered endangered. Thus, of eleven communities within Warra, four should be considered as threatened.

There are 18 taxa considered of conservation significance due to their occurrence on state and federal lists. Five species occur on the *NSW Threatened Species Conservation Act 1995*, one on the Federal *Environment Protection and Biodiversity Conservation Act* and 17 on RoTAP (Briggs & Leigh 1996).

The larger rock outcrops, and more significantly the Sara River Falls (on the south-eastern boundary of Warra NP) were the most significant sites in terms of rare or threatened species occurrences. The Sara River Falls had the highest concentration of significant species in a 10 ha area, many of which were not found anywhere else in the area. Rare or threatened species found within Warra NP and/or *Wattleridge* are:

Acacia brunioides subsp. *brunioides* (3RC-) is known from the Backwater area north to the McPherson Range near Toowoomba. This species has been recorded from Gibraltar Range NP, Mann River NR, Mt Barney NP, Mount French NP, Mt Greville NP and Nymboida NP. It was found in low numbers around the Sara River Falls within Warra NP.

Brachyloma saxicola (3RCa) (Hunter & Williams 1994; Richards & Hunter 1997) is known from Chaelundi north to Torrington. It is reserved within Guy Fawkes River NP, Bolivia Hill NR, Torrington SRA, Butterleaf NP, Gibraltar Range NP, Nymboida NP and Cathedral Rocks NP. This species is very abundant within both Warra NP and *Wattleridge*. The type location for the species is from *Wattleridge*.

Brasenia schreberi (3RC-) is known from a sporadic distribution throughout eastern Australia and also Africa, Asia and America. It is reserved within the nearby Llangotholin Lagoon NR and Crowdy Bay NP. Within Warra it was found only near the Sara River Falls.

Callitris oblonga subsp. *parva* (3VCa; Schedule 2, Vulnerable *TSC Act*) is known from the Mooraback area of Werrikimbe NP to Boonoo Boonoo NP. It is reserved within Werrikimbe NP, Basket Swamp NP and Boonoo Boonoo NP. Within the study areas this species was restricted to the banks of the Sara River where about 300 individuals are known, 50 of which are within Warra NP near the Sara River Falls.

Chiloglottis sphyrnoides (3RCa) (Copeland & Hunter 1999) is an orchid known from Barrington Tops NP in the south to just over the Queensland border. It is reserved within Werrikimbe NP, Guy Fawkes River NP, Barool NP, Gibraltar Range NP, New England NP, Capoompeta NP, Mann River NR, Western Washpool NP and Lamington NP. The species was found opportunistically within Warra NP in moist forest.

Cryptandra lanosiflora (3RCa) has been recorded from the Stanthorpe south to Werrikimbe NP. It is reserved within Girraween NP, Bald Rock NP, Boonoo Boonoo NP, Gibraltar Range NP, New England NP, Werrikimbe NP, Butterleaf NP, Mann River NR, Bolivia Hill NR and Torrington SRA. Populations of this species were found near the Sara River Falls and between Crown and Nightcap Mountains within Warra NP, though it was more common on outcrops on *Wattleridge*.

Eucalyptus camphora subsp. *relicta* (3VC-; Schedule 1, Endangered, *TSC Act*) is restricted to the Backwater area in NSW. Two populations are known within Warra NP with an estimated combined population size of around 10 000 individuals (Hunter 1996).

Eucalyptus codonocarpa (3RCa) (Hunter & Richards 1997) is known from Cathedral Rocks NP in the south to Girraween NP in Queensland. It is reserved within Cathedral Rock NP, Butterleaf NP, Gibraltar Range NP and Girraween NP. It is very abundant on outcrops and rocky river banks throughout both Warra NP and *Wattleridge*.

Eucalyptus dorrigoensis (3RCa) (Copeland & Hunter 1999) is known from the Dorrigo area north to Tenterfield. It is reserved within Boonoo Boonoo NP, Bald Rock NP, Demon NR, Dorrigo NP, Guy Fawkes River NP, Dorrigo White Gum FR, Western Washpool NP, Capoompeta NP and Butterleaf NP. It was found during a previous survey of Warra NP, but not found during this investigation.

Grevillea scortechinii subsp. *sarmentosa* (3VCi; Schedule 2, Vulnerable, *TSC Act*) is known from two areas in NSW, Backwater and Mann River NR, and is very abundant in both Warra NP and *Wattleridge*. It has been noted to germinate en-mass after fires in Warra NP, and some very large and apparently old stands, up to 2 m in height, are known from *Wattleridge*. Possibly as many as 20 000 individuals occur in the study area (Hunter 1996).

Hibbertia sp. aff. *obtusifolia* (2RCa) (Hunter & Clarke 1998) is only known from the Backwater, and the Parlour Mountains and Mt Yarrowyck west of Armidale (Nano 1996). The species was common within the study area and, based on counts made within survey sites and extrapolated, an estimated 10 000 individuals were found.

Kunzea bracteolata (3RC-) has been recorded from Mount Chaelundi north to the Stanthorpe area of Queensland. It is currently reserved within Girraween NP, Bald Rock NP, Boonoo Boonoo NP, Basket Swamp NP, Gibraltar Range NP, Guy Fawkes River NP, Limpinwood NR, Torrington SRA, Western Washpool NP, Butterleaf NP, Nymboida NP and Bolivia Hill NR. A small population was discovered around Nightcap Mountain in Warra NP.

Leionema ambiens (3VC-) (Copeland & Hunter 1999) occurs from the Stanthorpe area in Queensland south to Warra NP. The taxon is reserved within the Torrington SRA, Girraween NP, Bald Rock NP, Boonoo Boonoo NP, Gibraltar NP and the Demon NR. It was found only on Nightcap Mountain, in a few small populations in Warra NP.

Monotaxis macrophylla (Schedule 1, Endangered, *TSC Act*) is a small disturbance ephemeral species (Hunter & Bruhl 1997; Hunter 1998a; Hunter 2003b) with a highly stochastic distribution in NSW, but which is more common in Queensland. It has been found historically at Howell (Hunter 1998b), Torrington NR, Condobolin, Nymagee and Bega. Though not recorded in the original investigation of the *Bornhardtia* VCA (Hunter & Hunter 2003), it has since been discovered there (*pers. obs.*). This species was found in high numbers on two outcrops in Warra NP in 1995 (Hunter 1999).

Muehlenbeckia costata (3VCa; Schedule 2, Vulnerable, *TSC Act*) (Hunter et al. 1998) has a highly disjunct distribution and is only known from a handful of locations which include Mt Kaputar, Bald Rock, Backwater and the Blue Mountains (unconfirmed). This species is another disturbance ephemeral restricted to rock outcrops (Hunter et al. 1998; Hunter 2003b). It was estimated that around 5000 individuals were counted within Warra NP in 1995, however none are known at present due to its short life span and longlived seedbank (Hunter et al. 1998).

Persoonia procumbens (2RC-) is restricted to Backwater and the Round Mountain area east of Armidale. The species is reserved within Cathedral Rock NP. This taxon was found in 25% of all sites, and was abundant in five communities.

Pseudanthus divaricatissimus (3RCa) is known primarily south of Muswellbrook, south to Bega (Halford & Henderson 2003) with some disjunct locations as far north as Urbenville and Dubbo. This species was found on *Wattleridge* in only one location, where only three plants were seen (Hunter & Bruhl 1997).

Thelionema grande (3RCa) (Hunter & Copeland 1999) is known from south of Bundarra north to the Stanthorpe area in Queensland. The species is reserved within Girraween NP, Mt Barney NP, Bald Rock NP, Boonoo Boonoo NP, Gibraltar Range NP, Ironbark NR, Werrikimbe NP, Torrington SRA and Bolivia Hill NR. Within the study area the species was not found within Warra NP, but was found sporadically on rock outcrops within *Wattleridge*.

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Appendix 1: Flora of Warra National Park and *Wattleridge.*

Taxa found within the survey sites are scored according to their presence in each of the ten communities defined. Some taxa were found in previous surveys or opportunistically and therefore are not assigned to a specific community. Some orchid identifications may be identified in a broad taxonomic sense (sens. lat.). Nomenclature follows that of Harden (1990–1993) except where recent changes have occurred. Introduced taxa are indicated by *.

1 = *Leptospermum novae-angliae* – *Bursaria spinosa* – Riparian Scrub and Heath

2 = *Eucalyptus pauciflora* – *Eucalyptus nova-anglica* Woodland

3 = *Haloragis heterophylla* – *Carex inverse* Herbfield

4 = *Baeckea omissa* – *Leptospermum gregarium* Closed Wet Heath

5 = *Eucalyptus cameronii* – *Eucalyptus cameronii* – *Eucalyptus campanulata* Shrubby Open Forest

6 = *Eucalyptus radiata* – *Eucalyptus acaciiformis* Woodland

7 = *Eucalyptus cameronii* – *Eucalyptus caliginosa* Grassy Open Forest

8 = *Eucalyptus nobilis* – *Eucalyptus obliqua* Tall Open Forest

9 = *Eucalyptus obliqua* – *Eucalyptus nobilis* Tall Open Forest

10 = *Leptospermum novae-angliae* – *Kunzea obovata* – *Brachyloma saxicola* Open scrub and Closed Heath

TAXON	
FERNS & ALLIES	
Adiantaceae	
Adiantum aethiopicum	1, 2, 7, 8, 9
Cheilanthes sieberi subsp. *sieberi*	1, 7, 10
Pellaea falcata	10
Aspleniaceae,	
Asplenium flabellifolium	1, 10
Blechnaceae	
Blechnum cartilagineum	9
Blechnum minus	
Blechnum nudum	
Blechnum patersonii subsp. *queenslandica*	
Blechnum penna-marina subsp. *alpina*	4
Blechnum wattsii	1, 2, 4, 9
Doodia aspera	9
Cyathaceae	
Cyathea australis	8, 9, 10
Davalliaceae	
Davallia solida var. *pyxidata*	10
Dennstaedtiaceae	
Calochlaena dubia	5, 8, 9
Hypolepis glandulifera	
Pteridium esculentum	2, 3, 4, 5, 6, 7, 8, 9, 10
Dicksoniaceae	
Dicksonia antarctica	9
Dryopteridaceae	
Polystichum fallax	9
Gleicheniaceae	
Gleichenia dicarpa	10
Sticherus lobatus	
Lindsaeaceae	
Lindsaea linearis	5, 6, 7, 10
Ophioglossaceae	
Botrychium australe	
Polypodiaceae	
Platycerium bifurcatum subsp. *bifurcatum*	
Pyrrosia confluens var. *dielsii*	8
Pyrrosia rupestris	10
MONOCOTYLEDONS	
Anthericaceae	
Arthropodium milleflorum	4, 8, 10
Dichopogon fimbriatus	4
Laxmannia compacta	10
Laxmannia gracilis	10
Thysanotus tuberosus subsp. *tuberosus*	5, 6, 7, 8
Tricoryne elatior	4, 10
Asphodelaceae	
Bulbine bulbosa	
Commelinaceae	
Commelina cyanea	
Cyperaceae	
Baumea nuda	
Bulbostylis densa	10
Carex breviglumis	
Carex fascicularis	4
Carex gaudichaudiana	
Carex incomitata,	9
Carex inversa	3, 4, 7, 8, 9
Carex lobolepis	2, 4
Cyperus gracilis	7
Cyperus polystachyos	1
Cyperus sanguinolentus	1
Cyperus sphaeroideus	4
Cyperus unioloides	4
Eleocharis sphacelata	
Fimbristylis dichotoma	1, 10
Gahnia aspera	6, 7, 10
Gahnia sieberiana	1, 10
Gymnoschoenus sphaerocephalus	10
Isolepis hookeriana	4
Lepidosperma gunnii	4, 7, 8, 10
Lepidosperma laterale	1, 5, 7, 8, 10
Lepidosperma limicola	4, 6
Lepidosperma lineare	
Lepidosperma viscidum	
Rhynchospora brownii	1
Schoenoplectus mucronatus	1
Schoenus apogon	1, 4, 10
Schoenus melanostachys	5, 6
Scirpus polystachyus	4, 10
Erioeaulaceae	
Eriocaulon scariosum	4
Haemodoraceae	
Haemodorum planifolium	2
Iridaceae	
Patersonia fragilis	4, 6
Patersonia glabrata	4, 5, 7, 8, 10
Patersonia sericea	2, 5, 6, 7, 8, 10
**Sisyrinchium* sp. A	1, 3

Juncaceae	
**Juncus capitatus*	4
Juncus remotiflorus	10
Juncus subsecundus	2, 4
Juncus usitatus	
Juncus vaginatus	2, 3, 4, 6
Luzula densiflora	
Luzula flaccida	4, 7, 9, 10
Lomandraceae	
Lomandra confertifolia subsp. *pallida*	7, 8
Lomandra elongata	
Lomandra filiformis subsp. *coriacea*	8
Lomandra filiformis subsp. *filiformis*	7, 8, 10
Lomandra longifolia	1, 2, 4, 5, 6, 7, 8, 9, 10
Lomandra multiflora subsp. *multiflora*	2, 5, 7, 8
Luzuriagaceae	
Eustrephus latifolius	7, 8, 9, 10
Geitonoplesium cymosum	9
Orchidaceae	
Acianthus exsertus	9
Bulbophyllum elisae	
Caladenia cucullaya	
Caladenia fuscata	10
Calaena major	
Calochilus campestris	2, 10
Calochilus robertsonii	4, 7
Chiloglottis reflexa	10
Chiloglottis sphyrnoides	
Corybas fimbriatus	
Cryptostylis subulata	10
Dipodium variegatum	2, 5, 8
Dockrillia teretifolia	
Diuris abbreviata	
Microtis unifolia	2, 10
Prasophyllum brevilabre	8, 10
Pterostylis decurva	10
Pterostylis fischii	10
Pterostylis longifolia	10
Pterostylis reflexa	8
Pterostylis robusta	
Spiranthes sinensis subsp. *australis*	
Thelymitra pauciflora	
Phormiaceae	
Dianella caerulea var. *caerulea*	1, 4, 5, 7, 10
Dianella longifolia var. *stenophylla*	
Dianella revoluta var. *revoluta*	2, 4, 5, 6, 7, 8, 9, 10
Dianella tasmanica	10
Stypandra glauca	10
Thelionema caespitosum	4, 10
Thelionema grande	4
Poaceae	
Agrostis avenacea var. *avenacea*	2, 3, 4, 7
**Aira cupaniana*	1
Aristida calycina	
Aristida ramosa var. *speciosa*	1, 2, 4, 10
Aristida vagans	7
Austrodanthonia induta	3
Austrodanthonia laevis	4
Austrodanthonia monticola	1, 4, 6, 7, 8, 10
Austrodanthonia pilosa var. *pilosa*	10
Austrodanthonia racemosa var. *racemosa*	1, 2, 3, 4, 5, 6, 7, 8
Austrodanthonia tenuior	2
Austrafestuca eriopoda	4
Austrostipa aristiglumis	9
Austrostipa rudis subsp. *nervosa*	1, 2, 5, 7, 8, 9
Austrostipa rudis subsp. *rudis*	4, 7, 8
Austrostipa scabra	
Austrostipa setacea	10
**Bromus sterilis*	7
Cymbopogon refractus	1
Cynodon dactylon	7
Deyeuxia gunniana	7, 8
Deyeuxia parviseta var. *parviseta*	1, 7
Dichelachne crinita	1, 2, 7
Dichelachne inaequiglumis	1, 2, 4, 7, 8
Dichelachne micrantha	1, 2, 6, 7, 8
Dichelachne rara	
Dichelachne sieberiana	
Digitaria breviglumis	10
Digitaria ramularis	1, 8
Echinopogon caespitosus var. *caespitosus*	1, 2, 4, 5, 7, 8, 9, 10
Echinopagon mckiei	
Echinopogon ovatus	1, 4, 8
Elymus scaber var. *scaber*	
Entolasia marginata	7
Entolasia stricta	1, 2, 4, 5, 6, 7, 8, 10
Eragrostis benthamii	
Eragrostis elongata	1, 2, 3, 7
Eragrostis tenuifolia	10
**Hainardia cylindrica*	4
**Holcus lanatus*	2, 4
Imperata cylindrica var. *major*	1, 2, 4, 6, 7, 8, 9
Isachne globosa	1, 4, 8
Joycea pallida	
**Lolium multiflorum*	1, 10
Microlaena stipoides var. *stipoides*	1, 2, 4, 5, 6, 7, 8, 9, 10
Notodanthonia longifolia	1, 3
Oplismenus imbecillis	4, 8
Panicum effusum	10
Paspalidium constrictum	10
**Paspalum dilatatum*	1
Paspalum distchum	10
Pennisetum alopecuroides	4
**Phalaris paradoxa*	
Phragmites australis	2
Poa labillardieri	1, 2
Poa queenslandica	5, 7, 8
Poa sieberiana var. *sieberiana*	1, 2, 4, 5, 6, 7, 8, 9
Sacciolepis indica	4
Sorghum leiocladum	2, 4
Sporobolus creber	1
Sporobolus elongata	
Themeda australis	1, 2, 4, 5, 7, 8
Tripogon loliiformis	1, 10
**Urochloa panicoides*	1
**Vulpia ciliata*	
Restionaceae	
Baloskion fimbriatum	1, 2, 4, 6, 10
Baloskion stenocoleum	2, 4, 7
Empodisma minus	10
Lepyrodia anarthria	4, 6
Lepyrodia leptocaulis	4
Smilacaceae	
Smilax australis	5, 7, 8, 9
Xanthorrhoeaceae	
Xanthorrhoea glauca subsp. *glauca*	6, 10
Xyridaceae	
Xyris complanata	2, 4, 6
Xyris operculata	4

GYMNOSPERMS	
Cupressaceae	
Callitris oblonga subsp. *parva*	1, 2
DICOTYLEDONS	
Acanthaceae	
Rostellularia adscendens subsp. *adscendens*	7
Amaranthaceae	
Alternanthera sp. A	3
Apiaceae	
Actinotus gibbonsii	10
Centella asiatica	4
**Ciclospermum leptophyllum*	3
Daucus glochidiatus	8
Eryngium visculosum	
Hydrocotyle geraniifolia	4, 7, 8, 9
Hydrocotyle laxiflora	7, 8
Hydrocotyle peduncularis	4, 7, 8
Hydrocotyle tripartita	8
Oreomyrrhis eriopoda	8, 9
Platysace ericoides	5, 7, 8
Platysace lanceolata	5, 7, 10
Trachymene incisa subsp. *incisa*	2, 4, 7, 10
Trachymene sp. aff. *pilosa*	10
Araliaceae	
Polyscias sambucifolia	5, 7, 8, 10
Asclepiadaceae	
**Gomphocarpus fruticosus*	
Asteraceae	
Brachyscome microcarpa	10
Brachyscome nova-anglica	2, 4, 7, 8
Brachyscome scapigera	
Brachyscome stuartii	10
Brachyscome tenuiscapa var. *pubescens*	4, 7
**Carduus tenuiflorus*	10
Chrysocephalum semipapposum	2, 4, 7
**Cirsium vulgare*	7, 8
**Conyza albida*	1, 2, 3, 7, 8, 9, 10
**Conyza bonariensis*	3
Craspedia canens	
Craspedia variabilis	4, 7, 8
Euchiton gymnocephalus	7
Euchiton involucratus	
Euchiton sphaericus	1, 2, 4, 7, 8, 10
**Gnaphalium americanum*	1, 7
Helichrysum elatum	7
Helichrysum rutidolepis	7, 8
Helichrysum scorpioides	2, 4, 5, 7, 8
**Hypochaeris glabra*	3, 4, 7, 8
**Hypochaeris radicata*	1, 2, 4, 6, 7, 8, 9, 10
Lagenifera stipitata	6, 7, 8, 9
Leptochrysum albicans	
**Leucanthemum vulgare*	3
Olearia microphylla	
Olearia oppositifolia	10
Olearia stellulata	8
Ozothamnus diosmifolius	7
Podolepis jaceoides	
Podolepis neglecta	7, 8
Senecio diaschides	2, 4, 7, 8, 9
Senecio hispidulus	
Senecio lautus subsp. *lanceolatus*	9
**Senecio madagascariensis*	1, 2
Senecio prenanthoides	7, 8, 10

Sigesbeckia australiensis	9
Solenogyne bellioides	7, 8, 10
Solenogyne dominii	10
**Sonchus asper* subsp. *glaucescens*	
**Taraxacum officinale*	1
Vernonia cinerea var. *cinerea*	8
Vittadinia dissecta	1, 10
Xerochrysum bracteatum	7, 8, 9
Cabombaceae	
Brasenia schreberi	1
Campanulaceae	
Wahlenbergia ceracea	4, 6
Wahlenbergia communis	1, 2, 4, 7, 8, 9
Wahlenbergia gracilis	10
Wahlenbergia luteola	10
Wahlenbergia planiflora subsp. *longipila*	
Wahlenbergia stricta subsp. *stricta*	7, 8
Caryophyllaceae	
**Petrorhagia nanteuilii*	
Scleranthus biflorus	3, 8
Stellaria angustifolia	4
Stellaria flaccida	
**Stellaria media*	
Casuarinaceae	
Allocasuarina littoralis	7, 8
Allocasuarina rigida subsp. *rigida*	10
Allocasuarina torulosa	5
Celastraceae	
Maytenus silvestris	5, 7, 8
Chenopodiaceae	
Chenopodium pumilio	10
Chloanthaceae	
Chloanthes parviflora	10
Clusiaceae	
Hypericum gramineum	2, 4, 6, 7, 8
Hypericum japonicum	
Convolvulaceae	
Dichondra repens	2, 3, 4, 7, 8, 9
Dichondra sp. A	10
Crassulaceae	
Crassula sieberiana	1, 10
Dilleniaceae	
Hibbertia acicularis	4, 6, 10
Hibbertia aspera	
Hibbertia monogyna	10
Hibbertia obtusifolia	
Hibbertia riparia	2, 4, 7
Hibbertia rufa	7
Hibbertia scandens	
Hibbertia serpyllifolia	10
Hibbertia sp. B	5, 7, 8
Hibbertia vestita	
Hibbertia villosa	10
Droseraceae	
Drosera binata	4
Drosera burmannii	4
Drosera peltata	4, 10
Drosera spatulata	
Epacridaceae	
Brachyloma daphnoides subsp. *glabrum*	2, 7, 10
Brachyloma saxicola	1, 10

Epacris breviflora	
Epacris microphylla var. *microphylla*	2, 4, 6, 10
Epacris obtusifolia	
Leucopogon biflorus	1
Leucopogon lanceolatus var. *lanceolatus*	5, 7, 8, 9, 10
Leucopogon microphyllus	10
Leucopogon neoanglicus	1, 10
Lissanthe strigosa	
Melichrus procumbens	2, 4, 5, 7
Melichrus urceolatus	1, 7, 8
Monotoca scoparia	2, 4, 5, 6, 7, 8, 10
Escalloniaceae	
Quintinia sieberi	
Euphorbiaceae	
Monotaxis macrophylla	10
Phyllanthus virgatus	3, 7, 10
Poranthera microphylla	2, 4, 5, 6, 7, 8, 10
Pseudanthus divaricatissimus	10
Fabaceae	
Acacia brunioides subsp. *brunioides*	1
Acacia buxifolia subsp. *buxifolia*	5, 6
Acacia dealbata	
Acacia falciformis	5, 10
Acacia filicifolia	2, 4, 7, 8
Acacia fimbriata	1, 2, 7, 8
Acacia melanoxylon	9
Acacia mitchellii	5
Acacia myrtifolia	5
Acacia penninervis	
Acacia rubida	2, 7
Acacia siculiformis	1, 2
Acacia stricta	
Acacia ulicifolia	5, 6, 7, 8, 10
Acacia venulosa	10
Acacia viscidula	10
Aotus subglauca var. *subglauca*	2, 4, 6, 7, 10
Bossiaea neo-anglica	2, 5, 7, 8, 10
Bossiaea rhombifolia	10
Bossiaea scortechinii	2, 5, 7, 10
Cullen tenax	
Desmodium varians	1, 4, 7, 8, 9
Dillwynia phylicoides	4, 5, 6, 7, 8, 10
Dillwynia retorta	2, 4, 7
Dillwynia sieberi	1, 2, 4
Glycine clandestina	1, 2, 4, 5, 7, 8, 9
Glycine microphylla	7, 8
Glycine sp. A	4, 7
Glycine tabacina	2, 7, 8
Glycine tomentella	
Gompholobium huegelii	7
Hardenbergia violacea	5, 7, 8
Hovea purpurea	
Hovea heterophylla	2, 7
Hovea lanceolata	
Hovea pedunculata	1, 5, 10
Indigofera australis	8, 9
Jacksonia scoparia	7
Lespedeza juncea subsp. *sericea*	
Lotus cruentus	1
**Medicago arabica*	1, 3
**Medicago lupulina*	
**Medicago polymorpha*	
**Melilotus indicus*	1
Mirbelia confertiflora	1, 2, 10
Mirbelia pungens	6
Mirbelia rubiifolia	7

Pultenaea altissima	
Pultenaea linophylla	5, 8
Pultenaea myrtioides	
Sphaerolobium vimineum	
**Trifolium arvense*	
**Trifolium repens*	
**Trifolium subterraneum*	
Gentianaceae	
**Centaurium erythraea*	1, 3, 4, 8
**Centaurium tenuifolia*	
Geraniaceae	
Geranium neglectum	
Geranium potentilloides	
Geranium solanderi var. *grande*	4
Geranium solanderi var. *solanderi*	4, 7, 8, 9
Pelargonium inodorum	
Goodeniaceae	
Dampiera stricta	10
Goodenia bellidifolia subsp. *argentea*	10
Goodenia bellidifolia subsp. *bellidifolia*	4, 5, 6, 7
Goodenia hederacea subsp. *hederacea*	2, 4, 5, 6, 7, 8, 10
Scaevola hookeri subsp. *ramosissimus*	4
Velleia paradoxa	10
Haloragaceae	
Gonocarpus micranthus subsp. *micranthus*	10
Gonocarpus micranthus subsp. *ramosissimus*	2, 4, 6
Gonocarpus oreophilus	5, 9
Gonocarpus tetragynus	2, 4, 5, 6, 7, 8, 10
Gonocarpus teucrioides	2, 4, 7, 8, 9, 10
Haloragis heterophylla	3, 4, 8
Myriophyllum crispatum	1
Lamiaceae	
Ajuga australis	8, 10
Mentha diemenica	7, 8
Mentha satureioides	
Plectranthus graveolens	1, 8, 10
Prostanthera howelliae	
Prostanthera saxicola	
Prostanthera scutellarioides	5, 10
**Prunella vulgaris*	3, 4, 8
Teucrium corymbosum	
Lauraceae	
Cassytha glabella	
Lentibulariaceae	
Utricularia dichotoma	4
Linaceae	
Linum marginale	1, 3
Lobeliaceae	
Isotoma axillaris	10
Lobelia gracilis	
Pratia purpurascens	7, 8, 9
Loganiaceae	
Logania albiflora	1, 2
Loranthaceae	
Amyema miquelii	
Amyema pendulum	8
Muellerina eucalyptoides	
Lythraceae	
Lythrum salicaria	4

Malvaceae	
**Modiola caroliniana*	3
Myrsinaceae	
Rapanea howittiana	
Rapanea variabilis	8, 9
Myrtaceae	
Baeckea gunniana	
Baeckea omissa	2, 4, 6, 7
Callistemon pallidus	4, 6, 10
Callistemon pityoides	2, 4
Calytrix tetragona	1, 10
Eucalyptus acaciiformis	4, 6, 10
Eucalyptus caliginosa	1, 2, 4, 5, 7, 8, 10
Eucalyptus cameronii	5, 7, 8, 9
Eucalyptus campanulata	5, 6, 8, 9
Eucalyptus camphora subsp. *relicta*	2, 4
Eucalyptus codonocarpa	10
Eucalyptus dalrympleana subsp. *heptantha*	1, 2, 4, 7, 10
Eucalyptus dorrigoensis	
Eucalyptus eugenioides	8
Eucalyptus laevopinea	
Eucalyptus nobilis	4, 7, 8, 9
Eucalyptus nova-anglica	2, 4, 7
Eucalyptus obliqua	7, 8, 9
Eucalyptus pauciflora	2, 4, 7
Eucalyptus radiata subsp. *sejuncta*	5, 6, 7, 8, 9
Eucalyptus stellulata	7, 8
Eucalyptus viminalis	2, 7
Kunzea bracteolata	
Kunzea obovata	1, 10
Leptospermum arachnoides	
Leptospermum brevipes	1, 4, 6, 10
Leptospermum gregarium	2, 4
Leptospermum novae-angliae	1, 6, 10
Leptospermum polygalifolium subsp. *montanum*	
Leptospermum polygalifolium subsp. *transmontanum*	1, 2, 4, 8
Oleaceae	
Notelaea linearis	2, 10
Notelaea longifolia	9
Notelaea microcarpa var. *microcarpa*	
Notelaea ovata	2
Notelaea sp. A	8, 9, 10
Onagraceae	
Epilobium billardierianum subsp. *billardierianum*	3, 8
Epilobium gunnianum	1, 4
Oxalidaceae	
Oxalis chnoodes	2, 7, 8, 9
Oxalis perennans	
**Oxalis radicosa*	
Pittosporaceae	
Billardiera scandens var. *scandens*	5, 6, 7, 8, 10
Bursaria spinosa subsp. *obovata*	10
Bursaria spinosa var. *microphylla*	7
Bursaria spinosa var. *spinosa*	1, 2, 7, 8
Pittosporum multiflorum	
Rhytidosporum procumbens	
Plantaginaceae	
Plantago debilis	7, 8
Plantago hispida	
**Plantago lanceolata*	
Plantago varia	8, 9
Polygalaceae	
Comesperma ericinum	4, 10
Comesperma sphaerocarpum	4
Polygonaceae	
**Acetosella vulgaris*	3, 10
Muehlenbeckia costata	10
Persicaria decipiens	1, 3, 4
Persicaria hydropiper	1
Rumex brownii	3
Portulacaceae	
Calandrinia sp. A	1, 2, 10
Portulaca bicolor	10
Potamogetonaceae	
Potamogeton ochreatus	
Primulaceae	
**Anagallis arvensis*	
Proteaceae	
Banksia cunninghamii subsp. *cunninghamii*	4, 5, 6, 7, 8
Banksia integrifolia subsp. *integrifolia*	1, 2, 4, 5, 7, 8
Banksia spinulosa var. *collina*	10
Grevillea juniperina subsp. *allojohnsonii*	2, 4
Grevillea scortechinii subsp. *sarmentosa*	2, 5, 6
Hakea eriantha	4, 5, 8
Hakea laevipes subsp. *graniticola*	10
Hakea microcarpa	4
Lomatia fraseri	2, 4, 10
Lomatia silaifolia	2, 5, 6, 7, 8, 9, 10
Persoonia cornifolia	2, 4, 7, 10
Persoonia oleoides	5, 7, 8
Persoonia procumbens	2, 4, 6, 7
Persoonia sericea	7, 8
Petrophile canescens	2, 4, 5, 6, 7, 8
Ranunculaceae	
Clematis aristata	8, 9
Clematis glycinoides var. *glycinoides*	8
Ranunculus lappaceus	7, 8, 9
Rhamnaceae	
Cryptandra amara var. *amara*	1
Cryptandra amara var. *longiflora*	10
Cryptandra lanosiflora	1, 10
Pomaderris andromedifolia	
Pomaderris lanigera	5
Pomaderris nitidula	1, 5, 10
Rosaceae	
Acaena novae-zelandiae	3, 4, 8
Acaena ovina	
**Rosa rubiginosa*	
**Rubus chloocladus*	1
Rubus parvifolius	1, 2, 3, 4, 7, 8, 9
Rubiaceae	
Asperula conferta	
Coprosma quadrifida	7, 8, 9
Galium binifolium	7, 8
Galium ciliare	
Galium gaudichaudii	
Galium migrans	2, 4, 7, 8
Galium propinquum	7
Opercularia aspera	7, 10
Opercularia diphylla	1, 2, 7, 8
Opercularia hispida	4, 7, 8, 10
Pomax umbellata	5, 7, 8, 10

Rutaceae	
Boronia algida	5, 10
Boronia anemonifolia subsp. *variabilis*	10
Boronia microphylla	
Correa reflexa var. *reflexa*	1, 2, 9, 10
Leionema ambiens	10
Phebalium ozothamnoides	10
Zieria cytisoides	10
Zieria fraseri subsp. *compacta*	1, 10
Zieria laevigata	10
Zieria smithii subsp. *smithii*	8
Santalaceae	
Choretrum candollei	
Choretrum pauciflorum	2, 7
Exocarpos cupressiformis	10
Sapindaceae	
Dodonaea triquetra	5, 7
Dodonaea viscosa var. *angustissima*	1, 2, 10
Scrophulariaceae	
Derwentia arcuata	2
Gratiola peruviana	1, 2, 4
Stemodia glabella	
**Verbascum thapsus* subsp. *thapsus*	
**Verbascum virgatum*	
Veronica calycina	7, 8
Veronica plebeia	4, 9
Solanaceae	
Cyphanthera albicans subsp. *albicans*	10
Solanum aviculare	
Solanum brownii	
Solanum campanulatum	7, 8, 9
Solanum densevestitum	7, 8, 9
Solanum elegans	8, 9
Solanum linearifolium	
Solanum nobile	8
Solanum opacum	10
Solanum prinophyllum	
Stackhousiaceae	
Stackhousia monogyna	5, 10
Stackhousia viminea	2, 7, 8, 10
Stylidiaceae	
Stylidium graminifolium	2, 4, 5, 6, 7, 8
Thymelaeaceae	
Pimelea linifolia subsp. *linifolia*	2, 4, 5, 10
Pimelea neo-anglica	
Urticaceae	
Urtica incisa	
Verbenaceae	
**Verbena bonariense*	
**Verbena officinalis*	
Violaceae	
Hybanthus monopetalus	7, 8
Viola betonicifolia	7, 8, 9
Viola hederacea	2, 4, 8, 9
Winteraceae	
Tasmannia insipida	10

Vegetation of Culgoa National Park, central northern New South Wales

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***Abstract*:** The vegetation of Culgoa National Park (22 986 ha in area; 29°15′ S, 147°15′ E) in the central north of New South Wales, approximately 40 km west of Goodooga and adjoining the NSW/Queensland border, is described. Six vegetation communities are delineated based on UPGMA analysis of cover-abundance scores of all vascular plant taxa. These communities are mapped based on ground truthing and air photo interpretation. All communities are simple in structure being primarily woodlands, shrublands and grasslands. Communities described are: 1) *Eucalyptus coolabah* Woodlands, 2) *Muehlenbeckia florulenta* Shrubby Thickets, 3) *Eucalyptus coolabah – Acacia pendula* Woodlands & Grasslands, 4) *Eucalyptus largiflorens – Eucalyptus coolabah* Woodlands, 5) *Eucalyptus largiflorens – Alectryon oleifolius* Woodlands, 6) *Callitris glaucophylla – Eucalyptus populnea* Woodlands and Shrublands. A total of 240 vascular plant taxa were found of which 8% were exotic in origin. Conservation issues are discussed.

***Cunninghamia* (2005) 9(2): 275–284**

Introduction

Culgoa National Park (29°15′ S, 147°15′ E) is located near Weilmoringle, in the central north of New South Wales, approximately 40 km west of Goodooga and 80 km north of Brewarrina. The Park occupies 22 986 ha between the Culgoa River and the NSW/Queensland Border and adjoins Culgoa Floodplain National Park in Queensland (Fig. 1). The Park was dedicated in 1996. Recent additions, including the properties of *Dieninga, Pinegrove* and *Old Toulby* may increase the current reserve size by as much as 60%, but were not part of this investigation.

The Culgoa, Binnie, Bokhara and Narran Rivers are four branches that split from the lower reaches of the Balonne River south of St George, in Queensland. The Culgoa River eventually enters the Barwon River upstream from Bourke.

This paper reports on floristic survey and vegetation mapping (Hunter & Earl 2002) conducted for Bourke District of the NSW National Parks and Wildlife Service to provide baseline data for the Park, to map vegetation communities, and to provide information on the distribution of rare or geographically restricted or disjunct taxa, and associated conservation issues.

Climate

The climate of Culgoa National Park is semi-arid with an average annual rainfall of 375 mm (Dick 1993). The monthly rainfall is variable with a larger summer peak (in the longterm), but also a winter peak. Years with less than 250 mm often occur in pairs or threes causing drought conditions (Aldis 1987). Despite the large droughts of the late 1890s, the period prior to 1910 was wetter than from 1911 to 1947 (Gentilli 1971). Since that time the rainfall has been substantially higher and there has been an increase in the amount of summer rainfall (Pickard & Norris 1994). There are long hot summers and short cold winters. The average maximum and minimum temperatures for summer are 36°C and 21°C, and for winter are 18°C and 6°C, with an average of 76 frost days per year (AUSLIG 1990).

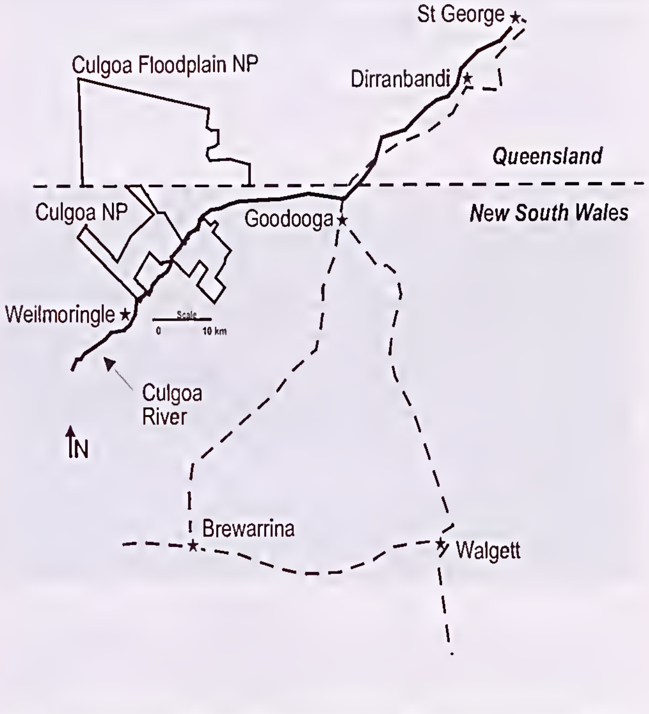

Fig. 1. Location of Culgoa National Park in central northern NSW.

Previous investigations

Early botanical work in north-western NSW includes Cambage (1900a; 1900b) around Bourke, Cobar, Bogan River and Nyngan; Turner (1903; 1905) Darling River area and Haviland (1911; 1913) for the Cobar area. Beadle (1948) produced the first vegetation map of the west, at 1: 1 024 000 scale in difficult conditions before the advent of aerial photographs (Beadle 1981; Beadle 1995). Pickard and Norris (1994) updated a large area of Beadle's map, based on reinterpretation of previous 1:250 000 map sheets, with greater ground truthing. Dick (1993) conducted an intensive floristic survey and produced a vegetation map of the Wombeira Land System which covers 32% of the Park. Though covering an extensive land system, this work used a variable plot size and the assemblages described were not based on statistical analyses, making cross comparisons with other areas difficult (Hunter et al. 2001). Other minor unpublished vegetation mapping products based on Land System types (Soil Conservation Service 1991) or on underlying soil type have been produced. The Departments of Infrastructure and Natural Resources, and Environment and Conservation have recently been mapping vegetation on 1: 100 000 map sheets that cover the Culgoa area; however these were not available for general release at the time of preparing this work.

Overall, most survey work, except for the most recent, have delineated plant communities on an a priori basis or circumscribed them based on field experience without numerical analysis. This has resulted in a number of unusual floristic units going unnoticed, and a number of other communities being defined on changes in structure or single overstorey taxa that, though of relevance to faunal assemblages and land management issues, often has little relevance to overall floristic resemblance.

Methods

In February 1999, 42 quadrats across Culgoa National Park, each 20 x 20 m in size were surveyed for vascular plants scored using the Braun-Blanquet (1982) cover abundance scale. Quadrats were placed using a stratified random method stratified by physiography. Analyses and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a, b). For final presentation of results all species and their relative abundance scores were used and the analysis performed using Kulczynski association measure which is recommended for ecological applications (Belbin 1995a, b) along with UPGMA clustering and the default PATN settings.

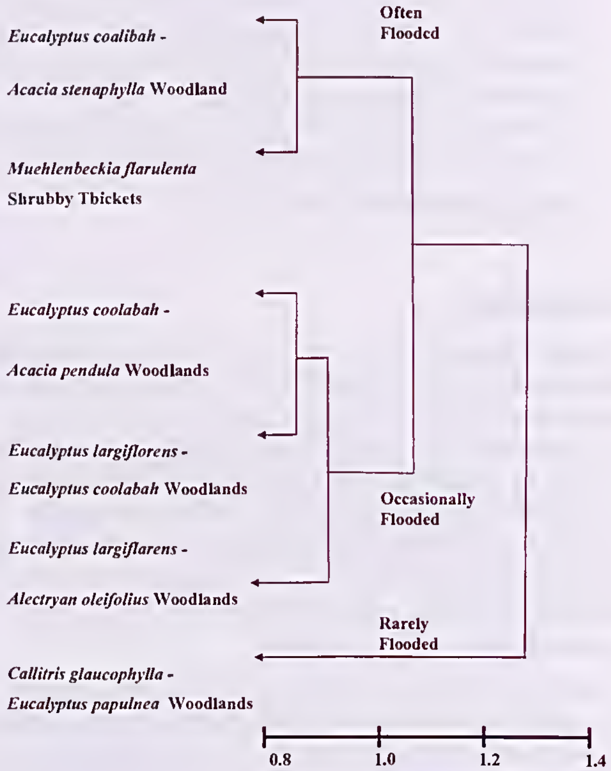
Eucalyptus coalibah -
Acacia stenaphylla Woodland
Muehlenbeckia flarulenta
Shrubby Thickets
Eucalyptus coolabah -
Acacia pendula Woodlands
Eucalyptus largiflorens -
Eucalyptus coolabah Woodlands
Eucalyptus largiflarens -
Alectryan oleifolius Woodlands
Callitris glaucophylla -
Eucalyptus papulnea Woodlands
Often Flooded
Occasionally Flooded
Rarely Flooded
0.8
1.0
1.2
1.4

Fig. 2. Summary dendrogram of the full floristic dataset of sites using the Kulczynski association and UPGMA fusion strategy and a beta value of -0.1. Communities have been defined at a dissimilarity level of 0.8.

Table. 1. Selected attributes of the six defined communities at Culgoa National Park. Note Lignum Open Shrublands could not be mapped effectively at this scale and so the proportion of the Park and the number of hectares are estimates.

Community	Number of sites	Richness per 400 m^2	Number of taxa	Number of introduced species	Proportion of Park	Area (ha)
C 1	13	11–39 (27)	98	2	30 %	6 754
C 2	2	24–26 (25)	40	3	2 %	460
C 3	12	23–42 (33)	121	4	44 %	10 125
C 4	5	21–33 (30)	71	3	12 %	2 698
C 5	4	16–38 (22)	57	2	8 %	1766
C 6	6	22–33 (26)	76	4	69 %	1 588

Mapping of vegetation community boundaries was based on the location of sites and their position within the multivariate analysis, air photo interpretation (1:50 000 scale air photos) and preliminary and subsequent ground truthing. Structural names follow Specht et al. (1995) and are based on the taxonomic identity of the most consistent species of the uppermost stratum. Good quality plant specimens were retained as vouchers by the Bourke District NSW NPWS (now Dept of Environment & Conservation) with duplicates of significant collections submitted to the National Herbarium of NSW, Sydney.

Results

Six communities were recognised at the dissimilarity measure of 0.8 (Table 1, Fig. 2). The major division implies a division between the often flooded and the more rarely flooded areas. In all 240 vascular plant taxa, from 58 families and 154 genera, were recorded from the collation of existing site data and subsequent sampling. 206 vascular plant taxa were recorded from the 42 quadrats of this survey. Approximately 8% (30) of all taxa were introduced in origin. The distribution of vegetation communities is shown in Fig. 3.

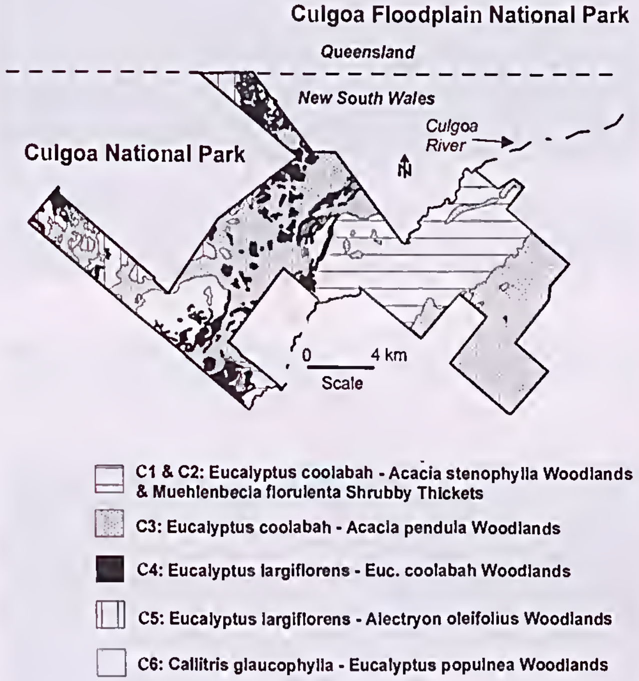
Culgoa Floodplain National Park
Queensland
New South Wales
Culgoa River
Culgoa National Park
N
0
4 km
Scale
C1 & C2: Eucalyptus coolabah - Acacia stenophylla Woodlands & Muehlenbecia florulenta Shrubby Thickets
C3: Eucalyptus coolabah - Acacia pendula Woodlands
C4: Eucalyptus largiflorens - Euc. coolabah Woodlands
C5: Eucalyptus largiflorens - Alectryon oleifolius Woodlands
C6: Callitris glaucophylla - Eucalyptus populnea Woodlands

Fig. 3. Map of vegetation communities for Culgoa National Park. Community 2 & 3 are combined in this map as they were not readily discernable on the scale of aerial photographs used for map production.

Vegetation communities

The communities within Culgoa National Park form structurally simple assemblages, low in height and foliage cover. Although simple, these associations exhibit distinct layering. Figures in brackets within each community description represent maximum and minimum values. The most common native taxa are listed in decreasing order of importance (based on summed cover scores).

Community 1: *Eucalyptus coolabah* (Coolibah) — *Acacia stenophylla* (River Cooba) — *Muehlenbeckia florulenta* (Lignum) Woodlands

Distribution: restricted to channeled floodplain on grey cracking clays but found throughout the entire centre of the Park on either side of the Culgoa River.

Structure: upper layer: 7–15 (–20) m; 10–20 (–60)% cover. ± Taller shrub layer: 2–3 m; 0–40% cover. Shrub layer (Lignum): 1–2 m; 40–80% cover. Herb layer: <1 m; 5–40 (–60)% cover. (Fig. 4)

Trees: *Eucalyptus coolabah, Acacia stenophylla, Atalaya hemiglauca, Alstonia constricta, Acacia coriacea.*

Shrubs: *Muehlenbeckia florulenta, Eremophila bignoniiflora, Einadia polygonoides, Sida trichopoda, Teucrium racemosum, Solanum esuriale, Sclerolaena muricata* var. *villosa, Sclerolaena calcarata, Atriplex muelleri, Myoporum platycarpum, Einadia nutans, Chenopodium auricomum, Sclerolaena tubata, Sclerolaena intricata, Sclerolaena bicornis.*

Ground cover: *Cyperus bifax, Paspalidium jubiflorum, Marsilea drummondii, Agrostis avenacea, Eragrostis setifolia, Plantago varia, Alternanthera nodiflora, Cyperus victoriensis, Sporobolus mitchellii, Ixiolaena brevicompta, Chamaesyce drummondii, Euchiton sphaericus, Panicum decompositum, Eragrostis lacunaria, Sporobolus caroli.*

Variability: this community can be further divided into those that are dominated by eucalypts often with *Acacia stenophylla* and *Eremophila bignoniiflora* and a dense *Muehlenbeckia florulenta* understorey. Other parts with a dense almost closed tree cover have a sparse *Muehlenbeckia florulenta, Eremophila bignoniiflora,* and *Acacia stenophylla* understorey with a dense grass/forb layer. The latter areas are due to large scale regeneration of *Eucalyptus coolabah* in the middle of this century (Dick 1993). *Eucalyptus camaldulensis* occurs sporadically within this community particularly close to river channels. The ground

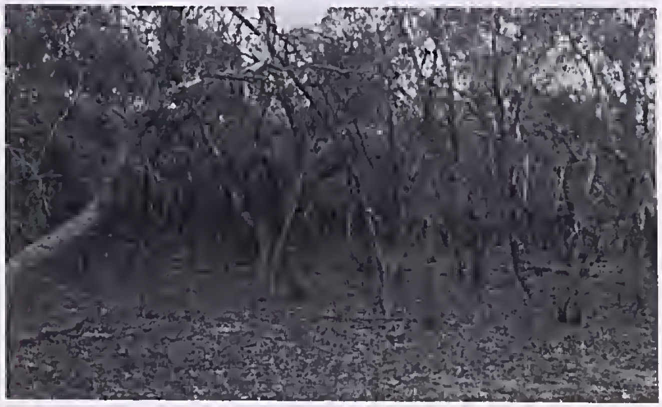

Fig. 4. Community 1. *Eucalyptus coolabah* and *Acacia stenophylla* Woodlands. Showing dense growth of *Eucalyptus coolabah.*

layer is diverse and varied and contains many ephemeral grasses and forbs that respond quickly to rainfall. Tall shrubs including *Acacia stenophylla* and *Eremophila bignoniiflora* are frequent. Where flooding occurs to a lesser degree, just away from the riverbanks and along some more minor channels *Eucalyptus coolabah* becomes prevalent as the overstorey species. This community grades into Community 2.

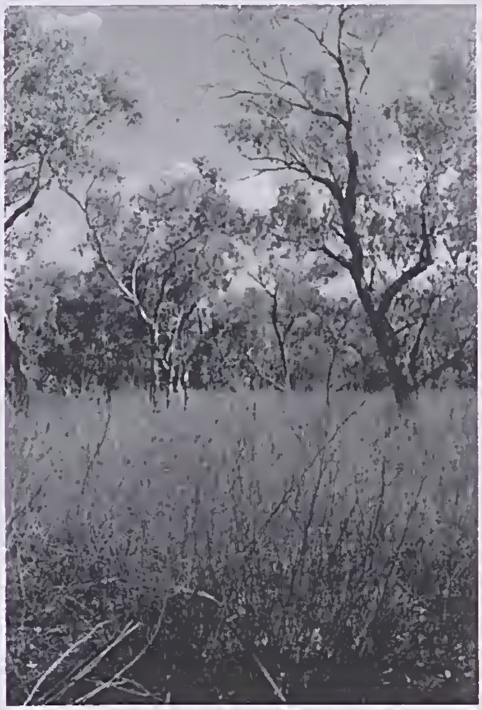

Fig. 5. Community 2: *Muehlenbeckia florulenta* Shrubby Thicket with scattered *Eucalyptus coolabah* becoming denser in the background.

Community 2: *Muehlenbeckia florulenta* (Lignum) Shrubby Thickets

Distribution: found in slightly elevated areas and minor drainage lines with fine light grey soils within the central parts of the reserve, closely associated with the low lying floodplains of the Culgoa River.

Structure: Upper layer: *c.* 15 m; 0–20% cover. Shrub (Lignum) layer: 1–1.5 m; 5–20% cover. Herb layer: 0.1–0.5 m; 50–65% cover. (Fig. 5)

Trees: *Eucalyptus coolabah, Acacia stenophylla.*

Shrubs: *Muehlenbeckia florulenta, Acacia coriacea, Sclerolaena muricata, Solanum stuartianum, Einadia nutans* subsp. *linifolia, Sclerolaena calcarata, Myoporum platycarpum, Myoporum montanum.*

Ground cover: *Eragrostis setifolia, Marsilea drummondii, Agrostis avenacea, Panicum decompositum, Eragrostis lacunaria, Chamaesyce drummondii, Pycnosorus thompsonianus, Pluchea dentex, Plantago varia, Panicum subxerophyllum, Malacocera albolanata, Haloragis glauca, Euchiton involucratus, Eryngium paludosum, Chloris truncata, Calotis scabiosifolia, Asperula cunninghamii.*

Variability: In less flood prone areas *Acacia stenophylla* occurs with a dense *Muehlenbeckia florulenta* understorey. The ground cover is normally dependent on the length of time since water was held. This community is closely associated with community 1 and many species are shared.

Community 3: *Eucalyptus coolabah* (Coolibah) — *Acacia pendula* (Weeping Myall) — *Acacia cambagei* (Gidgee) — *Eucalyptus largiflorens* (Black Box) Woodlands

Distribution: found on minor rises with sandy brown or red, red brown or light brown clay soils and grey cracking clay soils. Widespread away from the banks of the Culgoa River.

Structure: Upper layer: 5–10 m; 5–20%. Shrub (Lignum) layer: 1–1.5 m; 0–5%. Herb layer: 0.3–1 m; 50–80%.(Fig. 6)

Trees: *Eucalyptus coolabah, Acacia pendula, Acacia stenophylla, Acacia omalophylla, Acacia cambagei, Ventilago viminalis, Atalaya hemiglauca, Apophyllum anomalum, Alectryon oleifolius, Eucalyptus largiflorens.*

Shrubs: *Sida trichopoda, Muehlenbeckia florulenta, Sclerolaena bicornis, Atriplex muelleri, Sclerolaena calcarata, Chenopodium desertorum, Lotus cruentus, Cullen tenax, Maireana coronata, Salsola kali, Solanum esuriale, Einadia nutans* subsp. *eremaea, Sclerolaena tubata, Sclerolaena muricata, Chenopodium auricomum.*

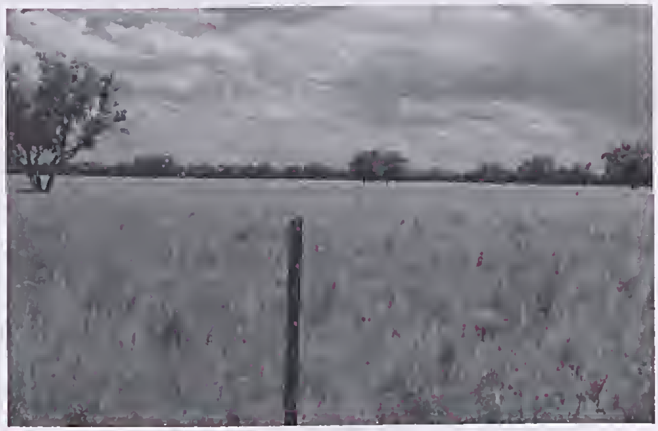

Fig. 6. Community 3: *Eucalyptus coolabah – Acacia pendula* Woodland & Grassland. This area showing natural grassland with low open woodland in the background.

Ground cover: *Eragrostis setifolia, Chloris truncata, Astrebla lappacea, Euchiton sphaericus, Sporobolus caroli, Agrostis avenacea, Plantago varia, Marsilea drummondii, Eragrostis lacunaria, Ixiolaena brevicompta, Dichanthium sericeum, Bothriochloa decipiens, Portulaca oleracea, Sporobolus actinocladus, Panicum subxerophyllum, Daucus glochidiatus, Alternanthera nodiflora.*

Variability: this community can be loosely further divided into two sub-assemblages. The first has a low open woodland structure and occurs primarily on sandy red/brown and light brown clay soils. The second includes open grasslands primarily on grey cracking clays in less elevated areas. These two sub-communities form a mosaic and clear field delineation may not be possible. Community 3 is closely associated, and intergrades with, Community 4, particularly in slightly elevated areas. *Eucalyptus largiflorens* becomes more important away from the main floodplain on slightly higher ground.

Community 4: *Eucalyptus largiflorens* (Black Box) — *Eucalyptus coolabah* (Coolibah) Woodlands

Distribution: found on slightly elevated sites periodically inundated but less so than communities 1–3. Soils are primarily light brown/grey clays but also grey and red clays. More commonly on the northern side of the Culgoa River and particularly on the north western boundary.

Structure: Upper layer: 8–10 m; 10–40% cover. Shrub (Lignum) layer: c. 1 m; 0–20% cover. Herb layer: 0.1–0.2 m; 20–70% cover. (Fig. 7)

Trees: *Eucalyptus largiflorens, Eucalyptus coolabah, Acacia stenophylla, Flindersia maculosa, Acacia pendula, Acacia cambagei, Acacia harpophylla.*

Shrubs: *Muehlenbeckia florulenta, Pimelea trichostachya, Sida trichopoda, Einadia nutans* subsp. *linifolia, Teucrium racemosum, Sida cunninghamii, Salsola kali, Myoporum montanum, Atriplex muelleri, Hibiscus trionum, Einadia polygonoides, Solanum esuriale, Sclerolaena intricata, Maireana coronata, Sclerolaena calcarata, Sclerolaena bicornis, Dissocarpus biflorus, Chenopodium desertorum.*

Ground cover: *Eragrostis setifolia, Sporobolus caroli, Marsilea drummondii, Chloris truncata, Tripogon loliiformis, Pluchea dentex, Plantago varia, Enneapogon gracilis, Agrostis avenacea, Euchiton sphaericus, Centipeda cunninghamii, Sporobolus actinocladus, Portulaca oleracea, Haloragis glauca, Eragrostis parviflora.*

Variability: dominants vary from *Eucalyptus largiflorens* to *Eucalyptus coolabah* with a number of wattles co-dominant. The importance of chenopods in the understorey varies and grasses may be more dominant than chenopods in a number of areas. Such small changes in over- and understorey species are due to minor changes in topography and flooding history (Hunter & Earl 1999).

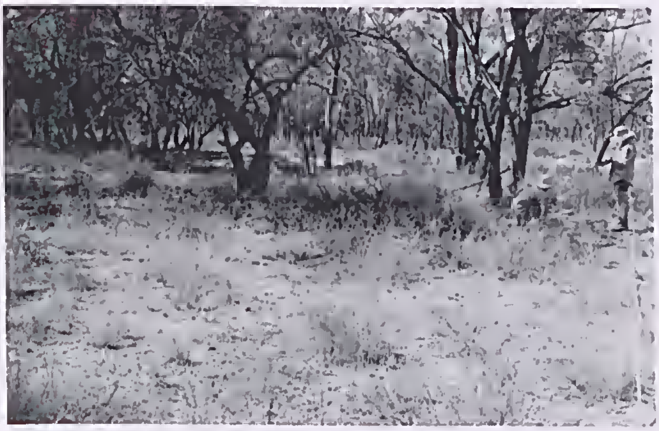

Fig. 7. Community 4: *Eucalyptus largiflorens – Eucalyptus coolabah* Woodland with small *Muehlenbeckia florulenta* shrubs and *Eragrostis setifolia* in the understorey.

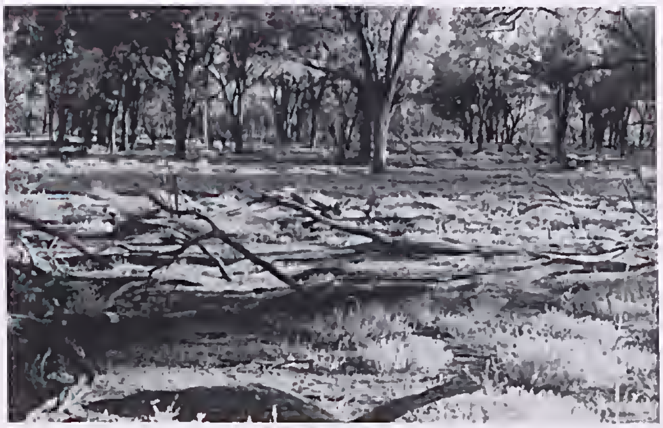

Fig. 8. Community 5. *Eucalyptus largiflorens – Alectryon oleifolius* Woodlands with an understorey dominated by various *Sclerolaena* species.

Community 5: *Eucalyptus largiflorens* (Black Box) — *Alectryon oleifolius* (Western Rosewood — *Acacia cambagei* (Gidgee) Woodlands

Distribution: found on slightly elevated areas with brown to reddish clay soils, some gilgai sites and light and friable grey clay soils. Common to the north of the Culgoa River particularly in the south western Park boundary.

Structure: Upper layer: 8–10 m; 10–30% cover. Middle (chenopod) layer: 0.4–0.7 m; 30–50% cover. Herb layer: 0.1–0.4 m; 5–50% cover. (Fig. 8)

Trees: *Eucalyptus largiflorens, Alectryon oleifolius, Acacia cambagei, Acacia stenophylla, Acacia pendula.*

Shrubs: *Sclerolaena calcarata, Sclerolaena bicornis, Chenopodium auricomum, Sclerolaena muricata* var. *villosa, Sclerolaena birchii, Myoporum platycarpum, Abutilon oxycarpum, Sclerolaena divaricata, Sclerolaena articulata, Hibiscus trionum, Einadia nutans* subsp. *eremaea, Dissocarpus biflorus, Chenopodium nitriaceum, Chenopodium desertorum.*

Ground cover: *Tripogon loliiformis, Sporobolus caroli, Eragrostis setifolia, Agrostis avenacea, Crassula sieberiana, Chloris truncata, Vittadinia eremaea, Portulaca oleracea, Euchiton sphaericus, Pycnosorus globosus, Plantago varia, Eragrostis lacunaria, Daucus glochidiatus, Cyperus bifax.*

Variability: chenopods are more prominent in disturbed sites where there is visible salt scalding. It is characterised by the increased importance of a chenopod understorey and absence of many of the co-dominant species shown in previous communities, such as *Eucalyptus coolabah* or the decreased importance of others such as *Acacia stenophylla*. Primarily this community is less frequently inundated than that of the previous two assemblages. Patches of *Acacia harpophylla* sporadically occur within this community.

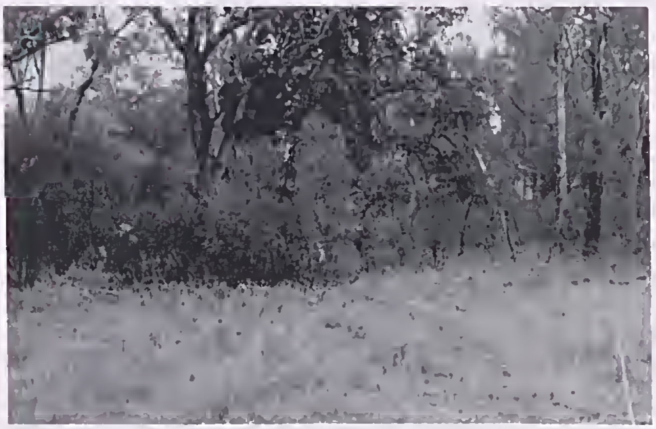

Fig. 9. Community 6: *Callitris glaucophylla – Eucalyptus populnea* Woodlands which has been cleared in the foreground but is relatively intact in the background.

Community 6: *Callitris glaucophylla* (White Cypress Pine) — *Eucalyptus populnea* subsp. *bimbil* (Bimbil Box) Woodlands

Distribution: found on elevated dunes with sandy reddish to orange soils or more rarely yellow contrast soils with a sandy topsoil. This assemblage is restricted to the south central and southern boundary of the Park.

Structure: Upper layer: 10–12 m; 15–30% cover. Middle layer: 1–3 m; 10–50% cover. Herb layer: < 1 m; 40–80% cover. (Fig. 9)

Trees: *Callitris glaucophylla, Eucalyptus camaldulensis, Eucalyptus populnea* subsp. *bimbil, Eucalyptus coolabah, Alectryon oleifolius.*

Shrubs: *Pimelea penicillaris, Dodonaea viscosa, Phyllanthus carpentariae, Sida cunninghamii, Einadia nutans* subsp. *eremaea, Chenopodium curvispicatum, Senna artemisioides, Myoporum montanum, Einadia polygonoides, Acacia penninervis, Sclerolaena ventricosa, Sclerolaena muricata, Salsola kali, Atriplex muelleri, Acacia salicina, Euphorbia sarcostemmoides.*

Ground cover: *Aristida psammophila, Eragrostis setifolia, Triraphis mollis, Panicum effusum, Rhodanthe diffusa, Nicotiana simulans, Eriachne aristidea, Wahlenbergia stricta* subsp. *alterna, Perotis rara, Chamaesyce drummondii, Sporobolus caroli, Setaria surgens, Podolepis longipedata, Evolvulus alsinoides, Eragrostis lacunaria, Enneapogon polyphyllus, Dichondra* sp. A, *Crassula sieberiana, Panicum decompositum, Oxalis chnoodes, Alternanthera denticulata.*

Variability: this community is the most distinctive of all those defined for Culgoa National Park. It has a number of unique indicative species. The major difference in stands is due to past grazing history and the state of subsequent recovery. Some areas are characterised by the prominence of 'woody weeds'.

Discussion

Periodicity of flooding is the most distinctive apparent gradient affecting community distribution within Culgoa National Park. Major changes in floristics are correlated with areas that are regularly flooded and retain water for some time; those that are flooded regularly, but do not retain water for extended periods; those that are only infrequently flooded and do not retain water for any length of time; and the dune areas which do not flood. The first two major groupings are closely associated, and intergradation occurs between all, whereas the third is very distinctive with little intergradation occuring with the others (Fig. 2).

Dick (1993) is the most directly comparable published work to this survey. In 65 sites recorded across the Wombeira Land System, includes the Narran and Culgoa Rivers, Dick found 230 native and exotic species, 175 during the survey and 55 additional from collation of over 21 years of previous survey records (1969–1988). He found an average of 20.4 species per site overall, with 25.4 in vegetation away from, and 20 within, channelised country - sites however were of a variable size but not smaller than 20 x 20 m. In the current survey, within the same land system and region, 109 species were found (within 15 sites), incorporating 43% of the total number known and 62% of those recorded by Dick. However, the average richness of sites was 26 species per quadrat which is considerably higher than that the 20.4 per quadrat recorded by Dick, using larger quadrats. In similar communities within the Narran Lake Nature Reserve, Hunter et al. (2001) recorded 120 species within 22 sites, with an average species richness of 12.6 per site, decidedly less than that recorded by Dick, and during this survey. These results reinforce the comments made by Hunter (1999) that, although similar communities occur at Narran Lake, they show far greater beta diversity (differences between site composition). In contrast those of the Culgoa region show a greater uniformity in associated species between sites. This correlation of higher beta diversity lowering alpha diversity was also shown in analysis of regional data by Hunter (2005).

Eleven communities within five structural classes were delineated qualitatively by Dick (1993), most of which are incorporated within the two communities *Eucalyptus coolabah* Woodlands and *Muehlenbeckia florulenta* Shrubby Thickets here. Although extra sampling may have increased the delineation of additional communities at Culgoa National Park, it is unlikely that the number of classes of vegetation described qualitatively by Dick could be derived from floristic analysis.

The communities at Culgoa National Park generally show greatest affinities with those in south-western Queensland (Neldner 1984) rather than those found further south in New South Wales.

Conservation issues

Benson (1989) lists the conservation status of most of the major plant communities in western New South Wales as poor or very poor. Only 2% of the Western Plains are conserved in National Parks or Nature Reserves (Benson 1991), with only 3% reserved in the north-western sector (Pickard & Norris 1994). About 44% of the vulnerable species in New South Wales, occur on the Western Slopes and Plains (Benson 1989, 1991). It has been estimated that up to 95% of the original native vegetation in the Murray Darling Basin has been changed by cropping or pasture improvement (Sivertsen & Metcalfe 1995).

The woodlands dominated by *Eucalyptus coolabah* on the Culgoa floodplain are the largest and least disturbed contiguous area of this vegetation remaining in New South Wales. Dick and Andrew (1993) report that clearing of extensive areas of Coolibah Woodland have already occurred, and that clear felling has generally left only small corridors, around 20 m wide along much of the Culgoa River. Elsewhere in New South Wales, riparian forests have been modified extensively by grazing and logging (Helman & Estella 1983; Scott 1992). The extent of *Eucalyptus camaldulensis* communities is misleading as they usually are of only one to three crown diameters wide in most situations, have a high boundary length to area ratio and are prone to weed infestations and disturbance (Sivertsen & Metcalfe 1995). Furthermore change in flooding regimes due to river regulation has led to a decline in recruitment and in the quality of the stands of Riparian Forests in many areas (Porteners 1993; Kingsford 2000).

Acacia harpophylla, Brigalow, forms distinct stands within community 5 *Eucalyptus largiflorens-Alectryon oleifolius* woodlands. Such stands are of significance due to impacts of the large scale clearing. *Acacia harpophylla* occurred widely in southeast Queensland with outliers in northern NSW

(Isbell 1962) and it is estimated that by 1951 about one third of the Brigalow lands had been cleared. In NSW some of the largest remaining stands of *Acacia harpophylla* country occur northwest of Bourke. *Acacia harpophylla* is usually restricted to 500 to 750 mm rainfall zones but may occur on alluvial clays when rainfall is lower (Neldner 1984). With an annual rainfall of around 375 mm in Culgoa National Park, Brigalow is restricted to low-lying clay soils there.

Callitris glaucophylla – Eucalyptus populnea woodlands similar to community 6 extend from Queensland to Victoria and South Australia, Western Australia and the Northern Territory (Beadle 1981) and are considered one of the most threatened communities in western New South Wales (Scott 1992). Associated species differ widely across its range (Porteners 1993). *Callitris glaucophylla* dominant assemblages in many areas of the state now occur only as remnants, with much of their understorey heavily grazed. Much of the area in the southeast of NSW has been extensively cleared and rabbits have reduced the regeneration capacity of the trees (Morcom & Westbrooke 1990; Fox 1991; Scott 1992; Porteners 1993). Under such conditions the soils are prone to salt scalding (Porteners 1993). The occurrence of this community within Culgoa National Park is of significance, as the mixed *Callitris - Eucalyptus populnea* assemblage is near its western range limit.

Culgoa National Park includes expanses of *Muehlenbeckia florulenta*. Lakebed cropping and subsequent clearing of *Muehlenbeckia florulenta* have become common practice in this and many other areas of the state (Aldis 1987; Briggs 1994) and graziers consider *Muehlenbeckia florulenta* a nuisance plant; experimental burns have been carried out to try to eradicate the species (Aldis 1987). It is estimated that 40% of *Muehlenbeckia florulenta* areas have been cleared in the last 20 years, with much of the remainder being grazed and disturbed by feral pigs (Scott 1992; Porteners 1993; Porteners et al. 1997). The occurrence of such a large expanse of this community within Culgoa National Park is of significance.

Eucalyptus largiflorens – Alectryon oleifolius – Acacia cambagei Woodlands (Community 5) appears to have very few direct correlates in the published literature. As circumscribed here, this community is restricted to the Culgoa River area, is not represented in any other reserves, and is of conservation significance. It is likely that the understorey of this community will change dramatically from season to season in particular under different flooding regimes and thus may require re-surveying to test their integrity and/or the changes in dominance and fidelity of species.

Culgoa National Park in conjunction with Narran Lake and Macquarie Marshes Nature Reserves conserve a significant representation of the floodplain floristic associations of the NSW mid northwestern plains. Most of the species recorded on the Wombeira Land System by Dick (1993) are found within these reserves. A large part (32%) of Culgoa National Park is floodplain vegetation on cracking clay soils — there are only minor occurrences of higher ground associations on red or orange soils. Woodland associations on higher ground may be worthy of addition to this reserve as they are under-represented within the region.

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Appendix: Flora of Culgoa National Park

Taxa found within survey sites are scored according to their occurrence in each of the six communities defined. Some taxa were found in previous surveys or opportunistically and therefore are not assigned to specific communities. * = exotic, O = opportunistic.

Communities
1 = *Eucalyptus coolabah – Acacia stenophylla – Muehlenbeckia florulenta* Woodlands
2 = *Muehlenbeckia florulenta* Shrubby Thickets
3 = *Eucalyptus coolabah – Acacia pendula – Acacia cambagei – Eucalyptus largiflorens* Woodlands & Grasslands
4 = *Eucalyptus largiflorens – Eucalyptus coolabah* Woodlands
5 = *Eucalyptus largiflorens – Alectryon oleifolius – Acacia cambagei* Woodlands
6 = *Callitris glaucophylla – Eucalyptus populnea* subsp. *bimbil* Woodlands

Taxon

Alismataceae	
Damasonium minus	O
Amaranthaceae	
Alternanthera angustifolia	2
Alternanthera denticulata	1
Amaranthus macrocarpus	O
Alternanthera nodiflora	1, 3, 5, 6,
**Gomphrena celosioides*	O
Ptilotus exaltatus var. *exaltatus*	3, 4
Ptilotus polystachyus var. *polystachyus*	3
Amaryllidaceae	
Crinum flaccidum	O
Anthericaceae	
Corynotheca licrota	6,
Apiaceae	
Daucus glochidiatus	3 5
Eryngium paludosum	1, 2, 3
Apocynaceae	
Alstonia constricta	1
Parsonsia eucalyptophylla	O
Asphodelaceae	
Bulbine semibarbata	1, 2, 3, 4
Asteraceae	
Brachyscome heterodonta var. *heterodonta*	2, 3, 4
Brachyscome melanocarpa	3
Brachyscome sp. *B*	3
Calotis latiuscula	1
Calotis scabiosifolia var. *scabiosifolia*	1, 2
Calotis scapigera	1, 3, 4
**Carthamus lanatus*	O
**Centaurea melitensis*	3 5
Centipeda cunninghamii	1, 3, 4, 5
Centipeda minima var. *lanuginosa*	4,
**Conyza bonariensis*	6,
Eclipta polyglossa	1
Epaltes cunninghamii	1, 3
Euchiton involucratus	2
Euchiton sphaericus	1, 3, 4, 5, 6
Gnaphalium diamantinense	2
**Hedypnois rhagadioloides* subsp. *cretica*	O
Leiocarpa brevicompta	1, 3, 6,
Leiocarpa semicalva var. *semicalva*	1, 3, 4
Millotia greevesii subsp. *greevesii* var. *glandulosa*	6,
Pluchea dentex	1, 2, 3, 4
Podolepis longipedata	6,
Pseudoghaphalium luteoalbum	O
Pycnosorus globosus	5
Pycnosorus thompsonianus	2, 3
Rhodanthe diffusa subsp. *leucactina*	6,
Rhodanthe floribunda	3, 5, 6
Senecio quadridentatus	3
Senecio runcinifolius	1
**Silybum marianum*	O

**Sonchus asper*	6
**Sonchus oleraceus*	2, 3 5, 6
**Verbesina encelioides* var. *encelioides*	6
Vittadinia condyloides	O
Vittadinia cuneata	3, 4
Vittadinia eremaea	5
Vittadinia pterochaeta	1, 3
Vittadinia pustulata	1, 3
Vittadinia sulcata	1, 4
Boraginaceae	
Cynoglossum australe	6
Brassicaceae	
Lepidium sagittulatum	4
Campanulaceae	
Wahlenbergia luteola	1, 3, 5, 6
Wahlenbergia stricta subsp. *alterna*	1, 3, 6
Wahlenbergia stricta subsp. *stricta*	1, 3
Capparaceae	
Apophyllum anomalum	3
Capparis mitchellii	O
Caryophyllaceae	
Polycarpaea corymbosa var. *minor*	3
**Spergula arvensis*	4
Stellaria angustifolia	1, 2, 4, 5
Chenopodiaceae	
Atriplex leptocarpa	3, 4
Atriplex muelleri	1, 3, 4, 5, 6
Chenopodium auricomum	1, 3, 4, 5, 6
Chenopodium cristatum	O
Chenopodium curvispicatum	5, 6
Chenopodium desertorum subsp. *desertorum*	1, 3, 4, 5
Chenopodium nitriaceum	1, 3, 4, 5
Dissocarpus biflorus var. *cephalocarpus*	3, 4, 5
Einadia hastata	1
Einadia nutans var. *eremaea*	1, 3, 5, 6
Einadia nutans var. *linifolia*	1, 2, 3, 4
Einadia nutans var. *nutans*	1
Einadia polygonoides	1, 3, 4 6
Maireana aphylla	3
Maireana coronata	1, 3, 4
Malacocera albolanata	2
Malacocera tricornis	3
Osteocarpum dipterocarpum	4
Salsola kali var. *kali*	1 3, 4, 5, 6
Sclerolaena articulata	1, 3, 5
Sclerolaena bicornis var. *bicornis*	1, 3, 4, 5, 6
Sclerolaena birchii	1, 5
Sclerolaena brachyptera	5
Sclerolaena calcarata	1, 2, 3, 4, 5
Sclerolaena divericata	1, 3, 5
Sclerolaena eriacantha	3, 5
Sclerolaena intricata	1
Sclerolaena intricate	1, 3, 4
Sclerolaena muricata var. *muricata*	1, 3, 5
Sclerolaena muricata var. *villosa*	1, 2, 3, 4, 5, 6
Sclerolaena stelligera	3, 4, 5
Sclerolaena tubata	1, 3, 4
Sclerolaena ventricosa	4, 6
Chloanthaceae	
Dicrastylis lewellinii	O
Commelinaceae	
Commelina cyanea	O
Convolvulaceae	
Convolvulus graminetinus	3, 4
Cuscuta campestris	4
**Cuscuta suaveolens*	2, 5
Dichondra sp. A	6
Evolvulus alsinoides var. *villosicalyx*	6
Crassulaceae	
Crassula sieberiana	3, 5, 6
Cucurbitaceae	
**Citrullus colocynthis*	6
Cupressaceae	
Callitris glaucophylla	6
Cyperaceae	
Cyperus bifax	1, 3, 5
Cyperus concinnus	1
Cyperus victoriensis	1, 3
Eleocharis pallens	1
Eleocharis plana	1
Fimbristylis dichotoma	O
Euphorbiaceae	
Chamaesyce drummondii	1, 2, 3, 4, 5, 6
Euphorbia sarcostemmoides	O
Petalostigma pubescens	O
Phyllanthus carpentariae	6
Fabaceae	
Acacia aneura	O
Acacia cambagei	O
Acacia coriacea	1, 2, 3, 4
Acacia harpophylla	5
Acacia melvillei	O
Acacia omalophylla	1, 3
Acacia oswaldii	O
Acacia pendula	3, 4, 5
Acacia penninervis	6
Acacia salicina	6
Acacia stenophylla	1, 2, 3, 4, 5
Acacia stowardii	O
**Astragalus hamosus*	6
Cullen tenax	1, 2, 3
Glycine canescens	6
Glycine latifolia	6
Indigofera linnaei	6
Lotus cruentus	3, 4
**Medicago polymorpha*	3
**Neptunia gracilis*	3
Senna artemisioides nothosp. *artemisioides*	6
Swainsona affinis	6
Frankeniaceae	
Frankenia serpyllifolia	O
Gentianaceae	
Centaurium spicatum	1, 2, 3
Centaurium tenuiflorum	6
Goodeniaceae	
Goodenia glauca	1, 3
Haloragaceae	
Haloragis aspera	4
Haloragis glauca var. *glauca*	2, 4
Hydrocharitaceae	
Ottelia ovalifolia	O
Juncaceae	
Juncus subsecundus	O
Lamiaceae	
Teucrium racemosum	1, 3, 4
Lomandraceae	
Lomandra leucocephala var. *leucocephala*	6
Lomandra patens	1
** Amyema miquelii*	1
Amyema miraculosum subsp. *boormanii*	1, 3

Lythraceae	
Lythrum salicaria	O
Malvaceae	
Abutilon fraseri	5, 6
Abutilon oxycarpum	1, 5
Hibiscus trionum	3, 4, 5
**Malvastrum americanum*	1, 3, 4, 5
Sida cunninghamii	1, 3, 4, 6
**Sida rhombifolia*	6
Sida sp. A	O
Sida sp. B	O
Sida trichopoda	1, 3, 4, 5, 6
Marsileaceae	
Marsilea drummondii	1, 2, 3, 4
Meliaceae	
Owenia acidula	O
Menyanthaceae	
Nymphoides crenata	O
Nymphoides geminata	O
Myoporaceae	
Eremophila bignoniiflora	1, 3, 5
Eremophila longifolia	1
Myoporum montanum	1, 2, 3, 4, 6
Myoporum platycarpum subsp. *platycarpum*	1, 2, 4, 5
Myrtaceae	
Eucalyptus camaldulensis	6
Eucalyptus coolabah	1, 2, 3, 4, 6
Eucalyptus largiflorens	4, 5
Eucalyptus populnea subsp. *bimbil*	6
Leptospermum brachyandrum	1
Melaleuca trichostachya	O
Nyctaginaceae	
Boerhavia coccinea	1, 3, 4, 6
Boerhavia dominii	4
Oleaceae	
Jasminum lineare	5, 6
Onagraceae	
**Oenothera mollisima*	2
Oxalidaceae	
Oxalis chnoodes	1, 3, 6
Plantaginaceae	
Plantago drummondii	3
Plantago varia	1, 2, 3, 4, 5
Poaceae	
Agrostis avenacea var. *avenacea*	1, 2, 3, 4, 5, 6,
**Aira cupaniana*	3
Amphibromus neesii	O
Amphipogon caricinus var. *caricinus*	O
Aristida longicollis	3, 6
Aristida psammophila	3, 6
Astrebla lappacea	3
Astrebla pectinata	3
Bothriochloa decipiens	3
**Cenchrus ciliaris*	O
Chloris truncata	1, 2, 3, 4, 5
Cynodon dactylon	1
Dichanthium sericeum subsp. *sericeum*	3
Digitaria brownii	3, 6
Digitaria divaricatissima	3, 6
Digitaria hystrichoides	3
**Echinochloa frumentacea*	O
Enneapogon gracilis	3, 4
Enneapogon polyphyllus	3, 6
Eragrostis dielsii	O
Eragrostis lacunaria	1, 2, 3, 5, 6
Eragrostis leptocarpa	3
Eragrostis parviflora	1, 3, 4
Eragrostis setifolia	1, 2, 3, 4, 5, 6,
Eragrostis speciosa	2, 3
Eriachne aristidea	3, 6,
Panicum decompositum	1, 2, 6
Panicum effusum	3, 6,
Panicum subxerophyllum	1, 2, 3
Paractaenum novae-hollandiae	1, 6,
Paspalidium distans	O
Paspalidium jubiflorum	1, 3, 4, 5, 6
Paspalidium rarum	O
Perotis rara	6
Setaria surgens	6
Sporobolus actinocladus	1, 3, 4
Sporobolus caroli	1, 3, 4, 5, 6
Sporobolus mitchellii	1, 2, 3
Themeda avenacea	3
Tragus australianus	1, 3, 5, 6
Triodia mitchellii	6,
Tripogon loliiformis	3, 4, 5
Triraphis mollis	3, 4, 6
Urochloa foliosa	O
Polygonaceae	
Muehlenbeckia florulenta	1, 2, 3, 4
Polygonum plebeium	O
Rumex tenax	1 3
Portulacaceae	
Portulaca oleracea	1, 2, 3, 4, 5
Rhamnaceae	
Ventilago viminalis	3
Rubiaceae	
Asperula cunninghamii	1, 2, 3
Psydrax oleifolium	O
Rutaceae	
Flindersia maculosa	4
Geijera parviflora	O
Santalaceae	
Exocarpos aphyllus	O
Santalum acuminatum	O
Sapindaceae	
Alectryon oleifolius	3, 5, 6
Atalaya hemiglauca	1, 3
Dodonaea viscosa var. *angustissima*	5, 6
Scrophulariaceae	
Stemodia glabella	1
**Verbascum virgatum*	6
Sinopteridaceae	
Cheilanthes sieberi subsp. *sieberi*	O
Solanaceae	
**Lycium ferocissimum*	O
Nicotiana simulans	6,
Solanum esuriale	1, 3, 4
Solanum ferocissimum	O
**Solanum nigrum*	5
Solanum sturtianum	1, 2, 4
Thymelaeaceae	
Pimelea penicillaris	6
Pimelea trichostachya	1, 3, 4
Verbenaceae	
**Verbena hispida*	1, 3
Violaceae	
Hybanthus monopetalus	O

The influence of vegetation structure and composition on invasibility by *Pinus radiata* in the Blue Mountains, NSW

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Abstract: The exotic tree species *Pinus radiata* D. Don (in the family Pinaceae) has successfully spread from commercial plantations into adjacent vegetation in southeastern Australia. Identifying factors facilitating spread will aid the control of current invasions and the prediction of future invasion events. The structure and composition of vegetation can have an important role in determining community resilience to invasion. Two dry eucalypt sclerophyll woodlands in the Blue Mountains west of Sydney known to be invaded by *Pinus radiata* were surveyed to investigate the influence of eucalypt presence, species diversity, species composition and vegetation cover on the extent and density of invasion. Relationships between community characteristics and the level of pine invasion were weak and variable. Pines were found growing in plots with 0–70% understorey cover and 5–90% ground cover, and in areas of both high and low eucalypt diversity and presence, illustrating the high invasion potential of *Pinus radiata*.

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Introduction

The impact of invading organisms on the biodiversity of ecosystems worldwide has been well documented (Hobbs & Mooney 1986, Vitousek et al. 1987, Mooney & Drake 1989, Mack & D'Antonio 1998, Groves & Willis 1999, Pimental et al. 2000). Much of the attention of invasion biologists has focussed on identifying attributes of invaders (Noble 1989, Mack 1992, Rejmanek & Richardson 1996) and invaded communities (Crawley 1987, Levine & D'Antonio 1999, Symstad 2000) in the hope of better understanding invasion mechanisms and aiding the mitigation of current invasions and prediction of future invasion events. However, efforts to identify a suite of characteristics common to invading organisms and vulnerable communities have largely been unsuccessful. In the absence of accurate generalisations regarding community invasibility, detailed site- and species-specific investigations continue to be useful approaches.

The exotic tree species *Pinus radiata* D. Don (in the family Pinaceae) has successfully invaded areas of native vegetation in southeastern Australia including Victoria (Minko & Aeberli 1986, cited in Richardson et al., 1994), New South Wales (Williams & Wardle 2005), Australian Capital Territory (Burdon & Chilvers 1977, Lindenmayer & McCarthy 2001) and South Australia (Virtue & Melland 2003). The spread of seed from large commercial plantations of the species into adjacent natural areas has led to the establishment of self sown individuals (wildlings) that are capable of dominating the landscape and negatively impacting the local ecosystem. Pine trees form dense stands and have the ability to significantly affect the structure and function of the native environment (Versfield & Van Wilgen 1986, Richardson et al. 1994a, Richardson et al. 1994b).

Factors governing the success of an invader include the number of propagules entering the environment (referred to as propagule pressure), characteristics of the new species and the susceptibility through time of the new environment to invasion (Lonsdale 1999). Plantations of *Pinus radiata* represent a large constant seed source and it is assumed that the number of propagules entering adjacent areas is high, and that seed availability is a non-limiting factor (Wardle et al., unpublished data). Key plant characteristics recognised as facilitating pine invasions include 1) the short juvenile period and short interval between large seed crops that results in early and regular production of seed and hence rapid population growth (Rejmanek & Richardson 1996); 2) the small mass and high wing loading of many pine seeds that can increase their dispersal capabilities (Van Wilgen & Siegfried 1986) and their potential for spread. Given this capacity of pines to invade, and the large seed source that plantations provide, it is likely that characteristics of the recipient habitat are having a large influence on invasion success.

A number of components of vegetation communities have been implicated in either facilitating or preventing the influx of invaders. One of the key and yet most controversial ideas relating to invasion theory is that areas of high species diversity are less prone to invasion (Elton 1958, Fox & Fox 1986). Communities with high species richness should in theory deplete limiting resources more effectively and thus prevent invaders from competing for those resources (MacArthur & Wilson 1967). However, this theory remains highly contentious and has more recently been challenged by the idea that the nature of the relationship between native and exotic species is highly scale dependent (Fridley et al. 2004, Herben et al. 2004). It is possible that the negative relationship between exotic and native species richness commonly observed in small scale experimental studies is an artefact of sample size and does not reflect any real negative interaction between the two. At larger scales plots will display greater variation in species richness and are likely to include more species of both native and invasive species resulting in a positive relationship between native and exotic species richness (Fridley et al. 2004).

Few studies have investigated the relationship between *Pinus radiata* invasion and species diversity. However, contrary to the theory that high native species diversity provides resistance to invasion by exotics, Lindenmayer and McCarthy (2001) found an increase in pine occurrence with increasing native tree species diversity within eucalypt forest remnants in southern New South Wales. South African fynbos, a shrubland vegetation very rich in species diversity is particularly susceptible to invasion by *Pinus* species (Richardson & Brown 1986). A greater understanding of the specific mechanisms of interaction between pines and indigenous vegetation at small scales may shed light on the ability of native species diversity to provide resistance to invasion.

Pinus radiata plantations in Australia are established across a broad range of climates and soil types with a variety of vegetation types that appear to differ in their susceptibility to invasion. Evidence from pine invasions in Australia suggests that forest types that vary in their canopy species will display differing levels of resistance to invasion. Lindenmayer and McCarthy (2001) reported significant differences in the probability of occurrence of *Pinus radiata* wildlings between forest types dominated by *Eucalyptus dives* and *Eucalyptus bridgesiana* which were more likely to be invaded, than areas dominated by other *Eucalyptus* species including *Eucalyptus viminalis* and *Eucalyptus pauciflora*. Other Eucalypt forests, such as those dominated by *Eucalyptus blakelyi* have been found to be relatively resistant to invasion (Minko & Aeberli 1986 cited in Richardson et al., 1994).

A recent study by Williams and Wardle (2005) found two dry eucalypt woodlands in the Blue Mountains, west of Sydney to be equally invadable by *Pinus radiata*. The authors recorded high pine densities of up to 1000 individuals per hectare and isolated pines growing at distances of up to 4 km from the plantation. Pine occurrence was highly variable with large scale aggregation of individuals (Williams and Wardle, 2005). Detailed investigations of specific structural and compositional components of vegetation at the study sites may provide insight into factors facilitating invasion. This study quantified eucalypt basal area, species diversity, species composition and vegetation cover within areas invaded by *Pinus radiata* to determine their influence on the extent and density of invasion.

Methods

Study sites

The study took place in two state forests situated in the upper Blue Mountains in the Central Tablelands of New South Wales. Newnes State Forest (150°12´E, 33°24´S; altitude 1000–1170 m) is located approximately 7.5 km north-east of Lithgow, NSW and encompasses a 51 year old, 2000 hectares *Pinus radiata* plantation. Lidsdale State Forest (150°3´E, 33°26´S; altitude 900–1000 m) is situated approximately 7 km north-west of Lithgow and includes a 46 year old, 580 hectares *Pinus radiata* plantation.

Average maximum temperatures in January, the hottest month are 23.2°C for Newnes State Forest and 24.6°C for Lidsdale State Forest. Average minimum temperatures for July, the coldest month, are -0.8°C at Newnes and -0.3°C at Lidsdale. Average annual rainfall is higher at Newnes (1072 mm) than at Lidsdale (870 mm). Seasonality is consistent at both sites with the majority of rain falling between January and March; July and August are the driest months (Bureau of Meteorology).

The two State Forests differ in their vegetation composition and soil type. The Newnes vegetation occurs on Sydney Basin Triassic sediments. Soils are characterised by earthy sands and shallow lithosols/siliceous sands (King 1993). Lidsdale is characterised by shallow stony lithosols and yellow podzolic soils derived from Devonian Lambie Group quartzites, sandstones, siltstones and claystones (King 1993).

The study area at Newnes State Forest has been described by Benson and Keith (1990) as 'Newnes Plateau Woodland' and is dominated by *Eucalyptus oreades* and *Eucalyptus sieberi*. The northern edge of the plantation is 'Blue Mountains Sandstone Plateau Forest' and is dominated by *Eucalyptus sieberi* and *Eucalyptus piperita*. This area was subject to a moderate intensity fire in December 2002. The understorey is an open shrub layer dominated by *Acacia terminalis, Hakea dactyloides, Banksia marginata* and a variety of *Leptospermum* species. The smaller shrub layer consists of *Boronia microphylla, Hibbertia obtusifolia, Lomatia silaifolia* and *Monotoca scoparia*. Common ground species were *Lomandra multiflora, Lomandra glauca* and the grass *Chionochloa pallida*. The vegetation at Lidsdale belongs to the "Mount Walker Complex" (Benson & Keith 1990). Vegetation structure is mainly woodland and dominated by *Eucalyptus mannifera, Eucalyptus dives* and *Eucalyptus bridgesiana*. The understorey is an open shrub layer with *Acacia dealbata, Leptospermum juniperinum* and *Leptospermum polyanthum*. Common ground species include *Lomandra longifolia* and *Lomandra multiflora* and the grass *Chionochloa pallida*.

Field Survey

The field survey was conducted between February and August 2003. At each site, pine occurrence was recorded within 20 m by 20 m plots located along six transects placed perpendicular to the plantation boundary (excluding transect 1 at Lidsdale which unavoidably ran parallel to a second plantation boundary when placed perpendicular to the first). Transects were placed on multiple borders of the plantation and ended when pines were no longer present or difficult terrain prevented further investigation. Transects ranged in length from 150 m to 2200 m at Newnes and from 200 m to 750 m at Lidsdale. Plots were placed in the nearest vegetation to the plantation edge, avoiding any forestry roads or fire breaks. The distance between plots varied from 100 m to 200 m to reflect changes in pine density. The height and diameter at breast height (dbh: 1.4 m) of *Pinus radiata* and eucalypt individuals were recorded for 28 plots at Newnes and 23 plots at Lidsdale. Plots were labeled with the letter 'N' or 'L' denoting Newnes or Lidsdale, followed by the transect number and a letter indicating the position of the plot within the transect. The dbh and height of tree species other than *Pinus radiata* were recorded for those with a dbh greater than 10 cm. The identification and percentage cover of dominant ground and understorey species were recorded for each plot.

The presence of forestry roads surrounding the plantation meant that the distance between the edge of a plantation and the location of the first plot in native vegetation typically ranged from 30 m to 70 m. However, for ease of analysis these plots are referred to as 'adjacent' plots located 50 m from the plantation. Plots greater than 50 m from the plantation are referred to as 'far' plots. Pine abundance is greatest within adjacent plots at both sites (Williams & Wardle 2005) indicating that propagule pressure is highest close to the plantation. At distances away from the plantation, where propagule pressure is reduced, it is more likely that factors such as vegetation are driving pine distribution.

Data analysis

To examine the relationship between species diversity and the level of invasion, correlations between Simpson's diversity index (S) and the number of species and pine abundance per plot were calculated using Pearson's correlation coefficient. Correlations were calculated for all plots combined, far plots, adjacent plots and plots combined on the basis of direction from the plantation.

Species composition data was analysed using PRIMER v5.2 (Plymouth Marine Laboratories 2001). Percentage cover estimates for each species within a plot were the basis of this analysis. Similarities in composition between samples (plots) were determined using non-metric multidimensional scaling (NMDS) using the Bray-Curtis similarity coefficient (Bray & Curtis 1957). The process is non-metric because samples are ranked in terms of their similarities. NMDS ordinations position samples on the basis of these ranks in multidimensional space. The closer samples are to each other, the more similar they are. To examine the relationship between species composition and the level of pine invasion, plots were categorised on the basis of pine occurrence. Pine abundance classes were, Low: < 20 pines, Medium: 21–40 pines, High: 41–60 pines and Very High: > 60 pines. Basal area categories were, Low: < 1m^2/ha, Medium: 1–5 m^2/ha, High: > 5–10 m^2/ha and Very High: > 10m^2/ha. If species composition is driving pine distribution the expectation is to see plots with similar species assemblages experiencing similar levels of pine invasion. On an NMDS plot this translates to a clustering of samples based on their pine abundance or basal area categories.

To establish if samples within pine categories were significantly different in their species composition, one-way ANOSIMs (PRIMER) were calculated. ANOSIM is analogous to ANOVA as it compares between-group and within-group variation using similarity ranks (Quinn & Keough 2002). An R statistic is calculated to test the null hypothesis that there is no difference between categories. R values greater than 0.75 indicate good separation of groups, R values greater than 0.5 suggest overlapping but clearly different groups, and values lower than 0.25 are barely separable (Clarke & Gorley 2001). Significance is determined by randomly reallocating samples within classes and calculating sample R values. The percentage of times that R is greater than the sampled R indicates whether the samples are significantly different (Clarke 1993). For any categories that were deemed significantly different from each other, SIMPER (PRIMER) analysis was performed. SIMPER (similarity percentages) identifies the species that are contributing most to the average dissimilarity between two groups (Clarke & Gorley 2001). To investigate patterns further, plots placed adjacent to the plantation were omitted from ordinations and the analysis repeated.

To examine the influence of vegetation cover on susceptibility to invasion, the relationship between total pine abundance, pine seedling abundance and percentage vegetation cover was determined using Pearson's correlation coefficient, for all plots, adjacent and far plots. It is important to realise that vegetation structure and density change with time and that present levels of cover may not represent the environment during the initial establishment of pines. Investigations of seedling abundance may provide more insight into the relationship between vegetation cover and the level of invasion as the number of seedlings in a plot will reflect the current susceptibility of the vegetation to invasion. The relationship between eucalypt basal area and pine basal area was calculated using Pearson's correlation coefficient. Eucalypt diversity within plots was also examined to determine their influence on pine occurrence.

Results

Species diversity

The relationship between Simpson's Diversity Index and pine occurrence was not significant at Newnes ($p > 0.01$) and significantly negative ($p < 0.01$) at Lidsdale (Fig.1). Negative correlations between pine abundance and species diversity were frequent (Table 1). At Newnes, significantly ($p < 0.01$) negative relationships were found between pine abundance and the number of species in all except the south-west and pooled far plots. Significant ($p < 0.05$) correlations were found between the Simpson diversity index and pine abundance in all but the southern plots and the far plots combined at Lidsdale.

Despite these significant results, the relationship between species diversity and the level of invasion was far from conclusive. Plots with high numbers of species experienced varying levels of pine invasion. At Newnes, two plots located at an equal distance and direction from the plantation contained the same number of species and experienced a more than two fold difference in pine abundance, containing 24 and 55 pine individuals respectively. This pattern was also observed at Lidsdale. Three plots located adjacent to the plantation boundary each had 16 species present, yet they contained 50, 24 and 16 pine individuals respectively.

Species composition

All species

NMDS ordinations of plant species composition at Newnes and Lidsdale revealed no indication of association of assemblages within pine abundance categories (Figs 2 and 3). ANOSIM showed that there was no significant difference among pine abundance classes for either Newnes ($R = 0.07$, $p = 0.251$) or Lidsdale ($R = 0.172$, $p = 0.051$). Categorisation of plots on the basis of basal area yielded similar results (Newnes $R = 0.127$, $p = 0.15$; Lidsdale $R = 0.011$, $p = 0.44$). Exclusion of plots adjacent to the plantation revealed a significant ($p < 0.05$) difference between pine basal area categories at Newnes (Fig. 4). SIMPER analysis showed that *Eucalyptus pauciflora* (25.78%) and *Eucalyptus piperita* (10.78%) were contributing most to the difference between medium and low basal area categories. Plots of medium pine basal area were characterised by high *Eucalyptus pauciflora* and low *Eucalyptus piperita* abundance. SIMPER also indicated that a greater abundance of *Eucalyptus piperita* in plots of low pine basal area was contributing most (14.5%) to the difference between high and low basal area categories.

Canopy species

NMDS ordinations of eucalypt species composition at Newnes and Lidsdale (Figs 5 and 6) showed no significant

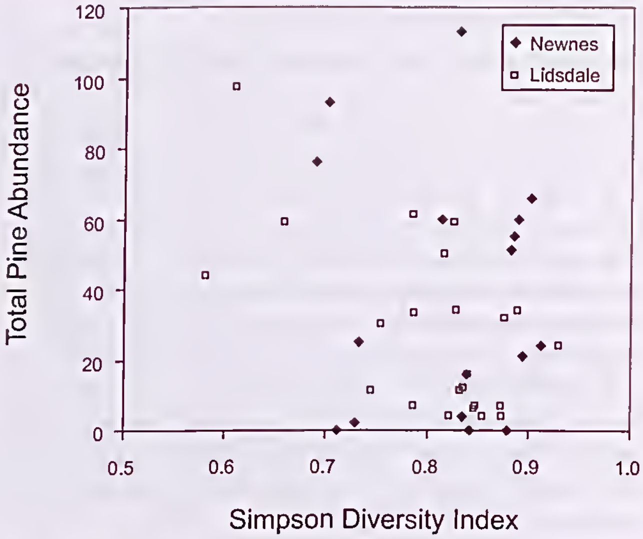

Fig. 1. Species diversity versus pine abundance for 17 plots at Newnes (r = -0.076) and 23 plots at Lidsdale (r = -0.59). This relationship was significant (p < 0.01) at Lidsdale.

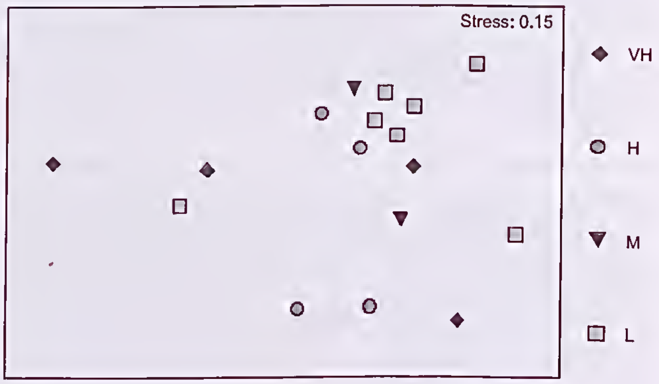

Fig. 2. NMDS ordination of plant species composition (excluding pines) at Newnes (Stress = 0.15). Pine abundance classes L: < 20 pines, M: 21-40 pines, H: 41–60 pines, VH: > 60 pines

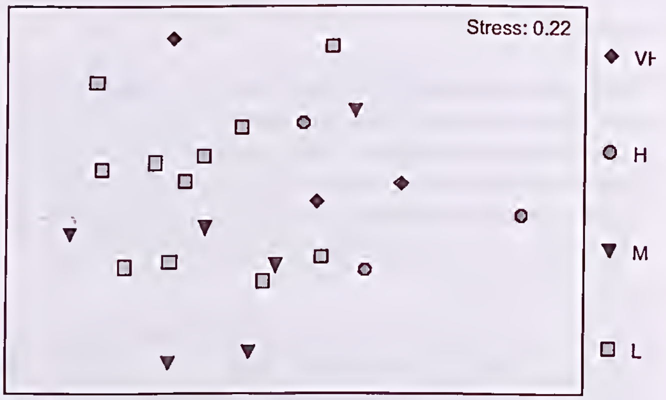

Fig. 3. NMDS ordination of plant species composition (excluding pines) at Lidsdale (Stress = 0.22). Samples are divided into pine abundance classes L: < 20 pines, M: 21–40 pines, H: 41–60 pines, VH: > 60 pines.

Table 1. Pearson's correlation coefficients for *P. radiata* abundance and the number of species and the Simpson diversity index.* Significant at $p = 0.05$, ** Significant at $p = 0.01$

	Plots (Sample size)	Number of species	Simpson diversity index
NEWNES	All (17)	-0.51*	-0.07
	Adjacent (8)	-0.65*	-0.27
	Far (9)	0.32	-0.08
	South-east (13) (Transects 1 and 2)	-0.55*	-0.17
	South-west (4) (Transects 3 and 4)	0.74	0.63
LIDSDALE	All (23)	-0.39*	-0.59*
	Adjacent (7)	-0.31	-0.85**
	Far (16)	-0.38	-0.34
	Eastern (5) (Transect 3 and 6)	-0.07	-0.97**
	Southern (8) (Transects 4 and 5)	-0.29	0.06

difference within pine abundance or basal area classes on the basis of eucalypt presence. Exclusion of plots adjacent to the plantation boundary did not reveal a significant influence of eucalypt composition.

When plots were pooled for each site, the overall relationship between pine and eucalypt abundance and basal area was negative at both sites (Table 2), suggesting competition between the two species. This result was only significant ($p < 0.01$) at Lidsdale. A consideration of this relationship within transects produced varying results. At Newnes, the relationship between eucalypt abundance and *Pinus radiata* abundance varied from a significantly ($p < 0.05$) negative interaction in transects 2 and 6 to no association in transect 1. At Lidsdale, correlations were highly negative with significant results observed for 3 of the 5 transects investigated. However, non-significant positive associations were also found for pine and eucalypt abundance within transect 1 and basal area in transect 4.

Mean eucalypt abundance in plots adjacent to the plantation was less than in far plots (Fig. 7). This result was significant for both Newnes ($F_{1,22} = 4.63; p = 0.043$) and Lidsdale ($F_{1,21} = 7.25; p = 0.014$). Mean eucalypt abundance in far plots was significantly greater at Newnes compared with far plots at Lidsdale ($F_{1,29} = 9.43; p = 0.005$). The mean eucalypt basal area in far plots at Lidsdale was 22.1 m²/ha, a value that is comparable with earlier studies of the area (Knights 1983), but significantly less than that recorded for Newnes (Basal area = 30.9 m²/ha; $F_{1,29} = 5.43; p < 0.027$).

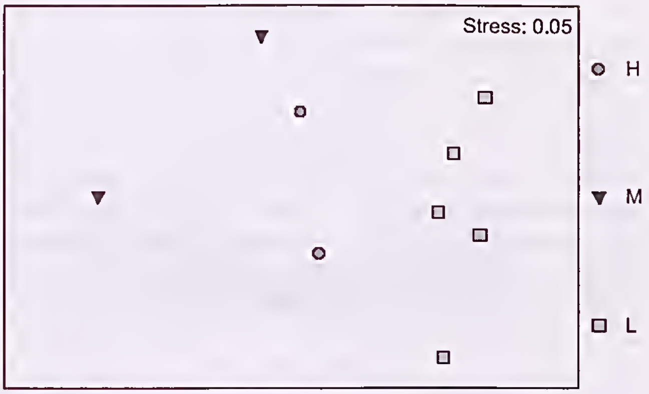

Fig. 4. NMDS ordination of species composition (excluding pines) within far plots at Newnes. Pine basal area classes Low: less than 1m²/ha, Medium: 1–5 m²/ha, High: 5–10 m²/ha (Stress = 0.05). ANOSIM showed significant differences between high and low (R = 0.509, $p = 0.048$) and between Medium and Low (R = 0.964, $p = 0.048$) basal area categories.

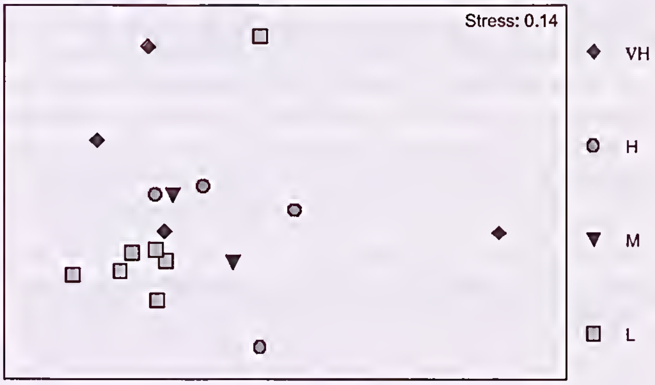

Fig. 5. NMDS ordination of Eucalypt species composition at Newnes (Stress = 0.14). L: < 20 *P. radiata* individuals, M: 20–40, H: 40–60, VH: > 60. ANOSIM revealed no significant separation of pine abundance (R = 0.172, $p = 0.09$) or basal area (R = 0.164, $p = 0.1$) classes.

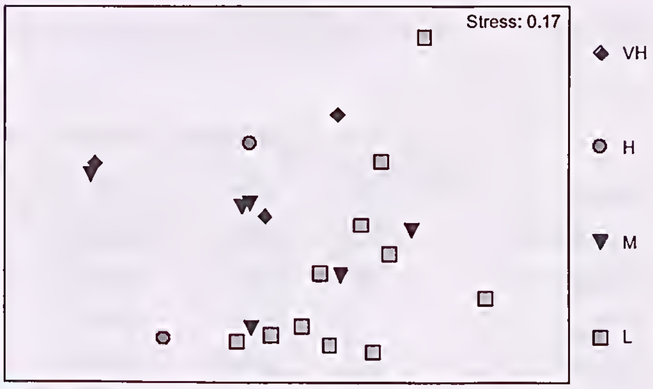

Fig. 6. NMDS ordination of Eucalypt species composition at Lidsdale (Stress = 0.17). L: < 20 *P. radiata* individuals, M: 20–40, H: 41–60, VH: > 60. ANOSIM revealed no significant separation of pine abundance (R = 0.135, $p = 0.12$) or basal area (R = 0.037, $p = 0.39$) classes.

The general negative relationship between pine and eucalypt abundance is illustrated in Figures 8B and 9B. Two of the most noticeable exceptions to this trend include plot 1F at Newnes and plot 5D at Lidsdale. Plot N1F was dominated by *Eucalyptus pauciflora* and had the highest eucalypt basal area of all plots (67m²/ha). Despite this large eucalypt presence, 76 pines were found growing here. Similarly, plot L5B, dominated by high numbers of *Eucalyptus mannifera* and *Eucalyptus dives* had 34 pines growing. Both of these plots were characterised by large numbers of pine seedlings and a few highly reproductive trees retaining large numbers of cones (620 cones and 60 seedlings in N1F; 131 cones and 22 seedlings in L5B; Wardle et al. unpublished data).

Eucalyptus composition varied notably across both study sites. Some plots were dominated by one species, while others contained up to 4 different species. *Eucalyptus oreades* dominated canopy composition at Newnes and was found throughout the study site appearing to have no influence on pine occurrence (Fig. 8). The next most common species, *Eucalyptus piperita,* found in association with *Eucalyptus oreades,* was restricted to plots with less than 9m²/ha of pine (Fig. 8). Plots with greater than 9m²/ha of pine and free of *Eucalyptus piperita* were all located in Transect 1. *Eucalyptus mannifera* was the most common species at Lidsdale occurring in plots with varying levels of pine abundance and basal area (Fig. 9). *Eucalyptus dives* and *Eucalyptus bridgesiana* were locally dominant in some areas. There appeared to be little influence of *Eucalyptus* composition on the pattern of pine occurrence at Lidsdale.

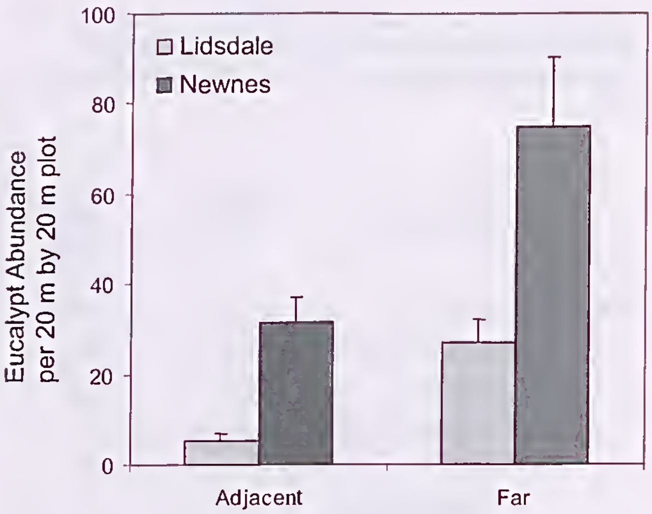

Fig. 7. Average (+SE) Eucalypt abundance in far and adjacent plots at both sites.

Vegetation structure

Levels of vegetation cover in the study plots ranged considerably, from 0 %–70 % understorey cover and from 5 %–90 % groundcover. Weak and varying relationships between vegetation cover and pine presence were found (Table 3). A significant (p = 0.018) positive correlation was found between canopy cover and pine seedlings in the adjacent plots at Lidsdale. However, this relationship was driven by the results of one plot which displayed the highest level of canopy cover (15%) and contained the highest number of seedlings (77).

Table 2. Relationship between eucalypt and pine occurrence. Number of plots (n) and Pearson's correlation coefficients for *P. radiata* and eucalypt basal area and abundance. Transects with two or less plots containing eucalypt and *P. radiata* data were omitted.
* Significant at $p = 0.05$, ** Significant at $p = 0.01$.

	NEWNES Correlation coefficients			LIDSDALE Correlation coefficients		
	n	Abundance	Basal Area (m²/ha)	n	Abundance	Basal Area (m²/ha)
All plots	24	-0.212	-0.215	23	-0.426*	-0.436*
Adjacent plots	9	-0.487	-0.420	7	0.431	-0.675
Far plots	15	0.081	-0.176	16	-0.337	0.183
Transect 1	7	-0.003	-0.430	6	0.653	-0.796*
Transect 2	6	-0.797*	-0.296	4	-0.996**	-0.278
Transect 3				3	-0.995*	-0.54
Transect 4				4	-0.734	0.729
Transect 5				4	-0.697	-0.871
Transect 6	6	-0.81*	-0.480			

Correlations between understorey cover and pine occurrence were inconsistent between sites. This relationship was negative across plots at Lidsdale and was strongest for total pines in the far plots ($r = -0.47$, $p = 0.065$). There was little influence of understorey cover on pine distribution at Newnes.

In general, only weak correlations between groundcover and pine occurrence were witnessed. A significant ($p < 0.05$) negative relationship between pine seedlings and groundcover was found in adjacent plots at Newnes. A significant ($p < 0.05$) positive relationship was found between total pine abundance and groundcover in far plots at Newnes.

Discussion

Significant negative relationships between species diversity and pine abundance were witnessed at both sites, providing some evidence for the hypothesis that species rich communities are resistant to invasion (Elton 1958, Fox & Fox 1986). However, the small sample size of plots considered and the varying level of pine abundance in plots with similar species composition suggest that this result must be interpreted with caution.

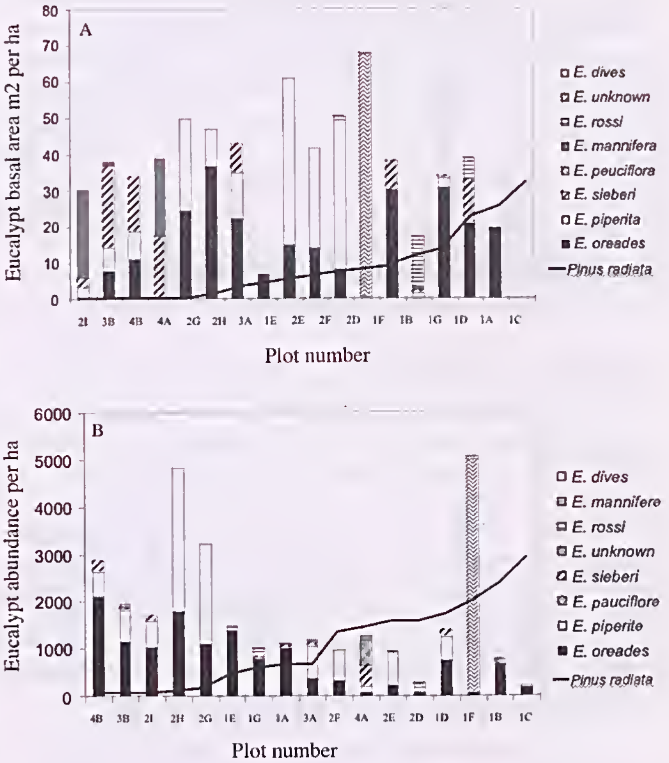

Fig. 8. Eucalypt composition versus increasing pine occurrence at Newnes. A. Basal Area m^2 per

Furthermore, plots located adjacent to the plantation were often characterised by low species diversity and high pine abundance resulting in strong negative relationships between the two. In contrast, this relationship was weak and non-significant in far plots. These results may reflect higher levels of disturbance in areas close to the plantation. Lower *Eucalyptus* abundance witnessed in adjacent plots and the presence of cut stumps suggests that selective logging has occurred within these areas. Forestry activities including vegetation removal and hazard reduction burning lead to increased light levels and reduced vegetation cover, which are known to facilitate pine establishment (Richardson et al. 1994b). Observations of *Pinus radiata* invasion in Chile have also indicated that the level of disturbance on the forest edge is an important determining factor of invasion success (Bustamante et al. 2003). An area subjected to recent fire and logging was found to be severely invaded while pine spread was limited to the forest edge of a fragment experiencing comparatively low levels of disturbance.

Table 3. Correlation coefficients for vegetation cover percentages and pine presence at Newnes and Lidsdale. Far plots are those located greater than 50m from the plantation boundary.
* Significant at $p < 0.05$

		NEWNES			LIDSDALE		
PLOTS		**All**	**Adjacent**	**Far**	**All**	**Adjacent**	**Far**
Canopy Cover	**Total pines**	-0.39	-0.21	-0.35	-0.04	0.49	-0.37
	Pine seedlings	-0.46	-0.36	-0.43	0.27	0.83*	-0.34
Understorey Cover	**Total pines**	-0.21	0.12	0.15	-0.32	-0.13	-0.47
	Pine seedlings	-0.14	-0.18	0.37	-0.36	-0.37	-0.42
Ground Cover	**Total pines**	0.02	-0.52	0.68*	-0.13	0.06	-0.47
	Pine seedlings	-0.24	-0.71*	0.59	-0.1	0.42	-0.24

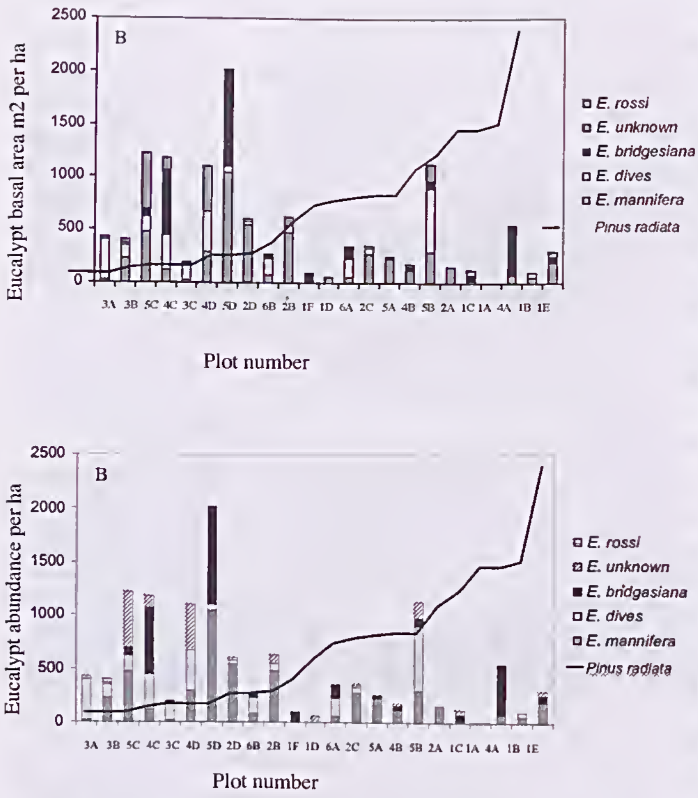

Fig. 9. Eucalypt composition versus increasing pine occurrence at Lidsdale. A. Basal Area m^2 per hectare and B. Abundance per hectar

The suppression of wildfires in areas surrounding plantations may also be influencing the distribution of pines with respect to the plantation. While mature pines are destroyed by high intensity fires, they are capable of surviving low intensity burns which do not scorch the crown (De Ronde 1982). Prescribed, low intensity fires implemented in areas close to the plantation in order to protect the resource are not of high enough intensity to destroy the pines. At distances away from the plantation high intensity wildfires are capable of killing larger adults. Natural occurrence of fires at a frequency high enough to prevent pines reaching maturity will hinder the success of pines in these areas.

The structure of a forest edge can be critical in determining the invasibility of an area and the removal of understorey vegetation can result in increased seed flux (Cadenasso & Pickett 2001). The process of plantation establishment involving the modification of vegetation in areas surrounding plantations, may be providing the disturbance that is thought to be necessary for the instigation of pine invasions (Richardson et al. 1994b). It is possible that disturbance close to the seed source is facilitating the initial establishment of pines adjacent to the plantation which may then make further spread into undisturbed areas possible. It is also a possibility that these results are confounded by distance. High pine abundances close to the plantation may be attributed to close proximity to the seed source rather than the effects of disturbance or low levels of species diversity.

The analysis of species composition provided little insight into determinants of pine distribution. Few notable relationships between species assemblages and the level of pine invasion were found. The sole significant result was a separation of pine basal area categories in far plots at Newnes on the basis of total species composition. Plots of medium pine basal area were characterised by a high abundance of *Eucalyptus pauciflora*. This species was only present in one plot suggesting that it is not responsible for wider differences in pine occurrence. Further, the small number of samples included in these categories demands discretion in the interpretation of this result.

The negative relationship between eucalypts and pines witnessed when all plots were pooled suggests the presence of interspecific competition. The greater eucalypt basal area within far plots at Newnes highlights a structural difference of the two vegetation types. If eucalypts and pines are competing for space, it follows that the higher eucalypt presence at Newnes may provide a natural barrier to invasion. This was not the case as mean pine basal area within far plots did not differ significantly between sites (Williams & Wardle 2005).

Contrary to the findings of Lindenmayer and McCarthy (2001), levels of invasion were similar across plots with differing dominant *Eucalyptus* species, indicating that canopy species composition had little influence on pine distribution. The absence of *Eucalyptus piperita* from plots with high pine basal area at Newnes would normally indicate a resistance of this species to invasion. However, plots free of the species were restricted to transect 1, an area characterised by reproductive trees and high seedling numbers. Spatial analysis of these areas revealed evidence for self propagation by wildlings (Williams and Wardle in preparation). This process of regeneration rather than any greater site suitability resulting from the absence of *Eucalyptus piperita* is likely to be responsible for the high pine abundance observed. Similarly, high pine numbers in plots with considerable eucalypt presence were also explained by the occurrence of reproductive trees and high seedling abundance.

Vegetation structure does not appear to be strongly influencing pine distribution. Correlations between percentage cover and pine abundance within all plots at both sites were inconsistent and mostly insignificant suggesting that factors other than vegetation components are driving pine establishment. Division of plots on the basis of distance from the plantation did strengthen some of these relationships returning three significant results, which require further explanation. A significant positive relationship between pine abundance and groundcover was found within far plots at Newnes. Range in groundcover within these plots was high (20–65%) allowing an investigation of its impact on pine presence. While high numbers of pines were associated with higher levels of groundcover, their presence can also be explained by the occurrence of highly reproductive trees within these plots, yielding large numbers of seedlings.

The significant negative relationship found between pine seedlings and groundcover within adjacent plots at Newnes is consistent with results from other studies. Lindenmayer and McCarthy (2001) found that the incidence of *Pinus radiata* wildlings increased significantly with decreasing groundcover. It is thought that reductions in groundcover diminish competition from neighbouring plants and facilitate pine establishment (Richardson et al. 1994b). A reduction in grass cover, known to compete with pine seedlings (Pearson 1942) can result in higher pine establishment rates. The level of groundcover in an area is often a reflection of other factors which are influencing susceptibility to invasion. It is possible that the negative relationship between seedlings and groundcover reflects high levels of disturbance close to the plantation. However, this relationship was highly influenced by one plot which experienced the lowest level of groundcover (5%) and the highest number of seedlings (86). The plot was located adjacent to the plantation and was highly disturbed, with several large fallen logs and an old trail-bike track. The high level of disturbance here has lead to increased light levels and reduced groundcover, creating an environment favourable to seedling establishment.

The significant positive relationship between pine seedlings and canopy cover witnessed in adjacent plots at Lidsdale must be interpreted with caution, as differences in percentage cover between plots were limited and it is improbable that they are capable of causing such large divergences in seedling abundance. An increase in cover from 10% to 15% is unlikely to be the sole factor generating a more than four-fold increase in seedling abundance.

The determining influence of vegetation on pine distribution observed by Rouget et al. (2001) was not witnessed in this study. Relationships between pine occurrence and community characteristics were weak and variable. Many of the patterns reported here can be explained by the presence of reproductive trees that are yielding high numbers of seedlings. Pines were observed growing in plots with vastly different levels of understorey and groundcover implying that these components of the vegetation do not prevent pine seedling establishment. Recent work has found that at local scales, propagule pressure is in fact a better determinant of invasive pine distributions than environmental variables including vegetation type (Rouget & Richardson 2003). Pine plantations provide a large constant seed source capable of exerting enormous propagule pressure on surrounding areas. In addition, highly reproductive wildlings represent an effective secondary seed source. It is possible that the pressure provided by both the plantation source and the first cohort of invaders is high enough to overcome any barriers to establishment created by vegetation (Richardson et al. 1994b) and suggests that wherever plantations are bordered by eucalypt forest, invasion events are likely. Almost one million hectares of pine plantations are cultivated in Australia placing a significant area of native vegetation under threat. Further study of a greater number of plantation sites will help investigate the relative roles of propagule pressure and vegetation structure and composition on invasion success.

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Bridging a biogeographic 'gap': microfossil evidence for the quillwort *Isoetes* on the Cumberland Plain west of Sydney during the early Colonial period

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Abstract: Fossil spores preserved on historical archaeological sites at Parramatta and Richmond indicate that two or more species of the quillwort genus *Isoetes* (family Isoetaceae) were growing along rivers on the Cumberland Plain, west of Sydney, during the late 18th and early 19th centuries. Perispore ornamentation indicates the parent plants were related to *Isoetes drummondii* A.Braun and *Isoetes muelleri* A.Braun: A possible third species produced microspores that are similar to, but much larger than, the spores produced by modern *Isoetes muelleri*. Apart from one dubious record, *Isoetes* has not been found in the Sydney flora or on the New South Wales Central Coast and Central Tablelands botanical subdivisions, but does occur in the Central Western Slopes, and botanical subdivisions to the north of Sydney (North Coast, Northern Tablelands) and south (Southern Tablelands, South-Western Slopes, South-Western Plains), as well as in other States. Our data indicate the present day disjunct distribution of *Isoetes* in New South Wales is most likely to be due to European settlement. The ability of quillworts to survive moderate levels of disturbance during the early Colonial period raises the possibility that remnant populations may still survive in protected areas on the Cumberland Plain.

***Cunninghamia* (2005) 9(2): 295–306**

Introduction

Organic-rich sediments, including buried topsoil and analogous cultural deposits on archaeological sites in Sydney, usually preserve diverse assemblages of fossil pollen and spores. Some of these represent native plants that are not present in the modern Sydney flora (cf. Carolin & Tindale 1994). For example, in 1996, numerous fresh-looking spores closely resembling those produced by the semi-terrestrial to freshwater aquatic quillwort species *Isoetes drummondii* A.Braun subsp *anomala* C.R.Marsden & Chinnock (family Isoetaceae) were recovered from sediments infilling an 1840s or older waterhole at Richmond on the Cumberland Plain west of Sydney (Fig. 1). The spores came from an approximately 1 m thick unit of laminated clays buried under about 0.5 m of late 19th and 20th century sands (Macphail 1996, 1999). Allochthonous pebbles, bottles and sherds of Victorian era blue and white pottery were scattered through the clay infill and demonstrate that the parent plants were alive sometime during the first five decades of European settlement of the Hawkesbury River district i.e. 1790–1840, when such waterholes provided water for stock.

This finding was wholly unexpected for two reasons: — firstly, *Isoetes* has not been conclusively recorded in the Sydney flora, and secondly, the closest known population of *Isoetes drummondii* subsp. *anomala* recorded in New South Wales occurs on the Southern Highlands, approximately 200 km southwest of Sydney (Carolin & Tindale 1994, Wilson 2000). Archaeological evidence showed that the c. 14 m long artificial waterhole had been dug in an existing depression, probably an abandoned high level channel of the Hawkesbury River, using a horse-drawn drag board (E.H. Higginbotham pers. comm.). Accordingly, it was uncertain whether *Isoetes* was growing along the middle reaches of the Hawkesbury River before European settlement in the 1790s or had been subsequently introduced, e.g. by the movement of stock from southern New South Wales, during the 19th century. The *Isoetes* collection held in the National Herbarium of New South Wales (NSW) includes specimens of *Isoetes drummondii* subsp. *anomala* collected from a 'marshy area near a stock reserve tank' at Henty on the South Western Slopes (NSW 410774).

We report here a second discovery of fossil *Isoetes* microspores in western Sydney, in buried silty soils on an historical archaeological site at the corner of George and Charles Streets, Parramatta, about 30 km southeast of Richmond (Fig. 2). The Parramatta microflora includes spores comparable to those produced by the two *Isoetes* species recorded in New South Wales and the age and context of the deposits are strongly against the parent plants being introduced by Europeans.

Present distribution and ecology of *Isoetes* in New South Wales

Only two of the fifteen living *Isoetes* species and subspecies currently recognised in Australia (Chinnock 1998) have been recorded in New South Wales: *Isoetes drummondii* A.Braun subsp *anomala* C.R.Marsden & Chinnock and *Isoetes muelleri* A.Braun (Wilson 2000). Both species are semi-terrestrial to freshwater aquatic herbs with leaves up to 30 cm long. Apart from one dubious specimen of *Isoetes muelleri* labelled 'ex Sydney' (NSW 234976), there are no herbarium records of either species from the Central Coast botanical subdivision, including Sydney, or the Central Tablelands botanical subdivision to the west. The closest known populations of *Isoetes drummondii* subsp. *anomala* occur on the Southern Tablelands and South-Western Slopes botanical subdivisions, whilst *Isoetes muelleri* is also found on the Central Western Slopes at Lake Cowal (NSW426409), and in the South-Western Plains, North Coast and Northern Tablelands botanical subdivisions (http://plantnet.rgbsyd.nsw.gov.au).

Isoetes drummondii also occurs in southwestern Western Australia, southeastern South Australia, Victoria and Tasmania (Fig. 3): *Isoetes muelleri* is even more widely distributed, with populations extending into the arid interior of Western Australia as well as the Northern Territory, northern South Australia and southwestern Queensland (Fig. 4).

Chinnock (1998) cites *Isoetes drummondii* as being widespread in swamps and seepages, where it may be fully submerged or emergent in very open situations. The species frequently occurs on disturbed sites and can be found growing in wet patches along fire breaks in pine plantations in South Australia and Victoria. Analogous populations in New South Wales and Tasmania occur in wet ditches along railway lines, and along roadsides and in drains respectively. *Isoetes muelleri* occupies a much broader range of habitats, from permanent subalpine tarns in Tasmania, to ephemeral swamps and rock pools in Central Australia.

Archaeological setting

Early Colonial Parramatta was largely built on a flight of Late Quaternary river terraces near to the tidal (and initially navigable) limits of the Parramatta River. Triassic shales (Ashfield Shale), which form the underlying bedrock, outcrop along the riverbanks. Remnants of the Holocene floodplain, formed after postglacial sea levels stabilised about the present day position about 6000 years ago level, occur up to 2 m elevation on both sides of the river (Mitchell 2003).

Archival and borelog evidence indicate that the pre-settlement topography of the Holocene floodplain was highly irregular due to the prevalence of levee-bank remnants (reduced to mounds) and back-swamp hollows (Lawrie 1982): Some of the more permanent freshwater ponds were used as a domestic water supply by the early Colonial period residents. Higher terraces above 5–6 m above sea level, including the terrace occupied by the George and Charles Streets archaeological site, are more likely to have formed during the Last Interglacial period some 120 000 years ago and any remnant fluvial landforms are highly subdued. Soils on these higher level terraces are predominantly highly leached, brownish grey to yellow-brown fine quartz sands or gradational red earths (Mitchell 2003). Both the A_1 and A_2 horizons have been strongly bioturbated by cicada larvae, with infilled burrows reaching to an average depth of about 35 cm and occasionally to 50–60 cm depth below ground level (Mitchell 2003).

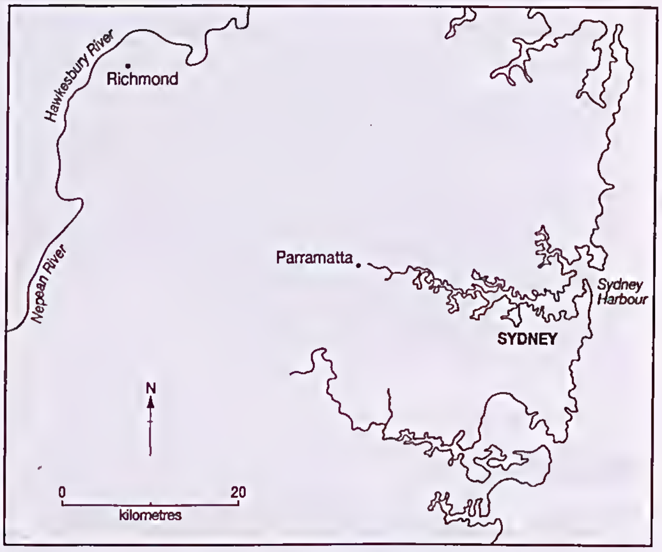

Fig. 1. The location of Parramatta on the Parramatta River and Richmond on the Hawkeasbury River west of Sydney.

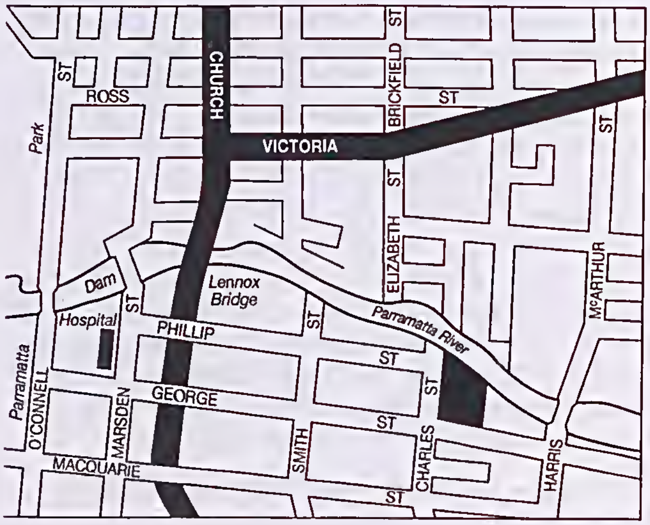

Fig. 2. The location of the George and Charles Street Parramatta archaeological site (shaded black) in relation to the upper Parramatta River.

Table 1. Relative pollen abundance, George and Charles Streets Parramatta archaeological site

Relative abundance calculated as a percentage of the total pollen and spore excluding algae.
+ equals values < 1%. Values based on pollen sums of less than 200 are statistically unreliable

TAXON	**Allotment 69**			**70**	**72**
	ACN 2425	**ACN 2430**	**ACN 2484**	**ACN 2202**	**ACN 2791**
Reworked Triassic pollen & spores	+		4%	1%	
Concentration (10^3 grains per gram)	0.3	0.3	1.3	1.8	0.15
POLLEN SUM (excluding Triassic spp.)	172	140	190	268	104
Definite exotics					
Malvaceae (cf *Hibiscus*)				+	
Pinaceae				9%	
Plantago lanceolata-type	+			1%	
Polygonum aviculare			+	+	
Poaceae (> 60 µm)	+			3%	
Probable exotics					
Apiaceae				+	
Arecaceae				+	
Asteraceae: high spine-types)				+	
Bidens-type				+	
Brassicaceae (*Rapa*-type)			+	+	
Chenopodiaceae			2%	16%	
Liguliflorae (*Taraxacum*-type)	4%	2%	2%	5%	6%
Rosaceae (*Fragaria*-type)			+		
Rosaceae (*Malus*-type)			3%		
Rosaceae			+		
Stellaria				+	
Non-local native taxa					
Cyathea		+		5%	2%
Dicksonia			+	2%	
Podocarpus				+	
Native trees & shrubs					
Acacia (granular)					11%
Acacia (non-granular)	+	1%			
Allocasuarina/Casuarina	11%	15%	21%	4%	11%
Banksia					1%
Dodonaea viscosa-type			+		
Eucalyptus	62%	49%	42%	6%	65%
Leptospermum spp.				+	
Monotoca			+		
unidentified Myrtaceae				2%	
unidentified tricolpates			+	+	
unidentified tricolporates			3%	+	
Native Herbs					
Asteraceae: low spine types		+		+	1%
Brassicaceae	+			+	
Cyperaceae	+		+	15%	
Lemna	1%				
Poaceae (< 50 µm)	10%	6%	13%	7%	1%
Ranunculus		+			
Restionaceae			+	+	
Native ferns & fern allies					
Calochlaena	+	3%	+	+	
Isoetes drummondii-type	2%	4%	+		
Isoetes muelleri-type				+	
Isoetes cf. *muelleri*					1%
Microsorium				+	
Monolete ferns			+	7%	
Pteris		+		+	
Pyrrosia-type	+			+	
Trilete ferns	2%	3%	2%	3%	1%
Liverworts & mosses					
Cingulatisporites spp. (Anthocerotae)	3%	9%	2%	3%	
Rudolphisporis rudolphi (Ricciaceae)	+	3%	+	3%	

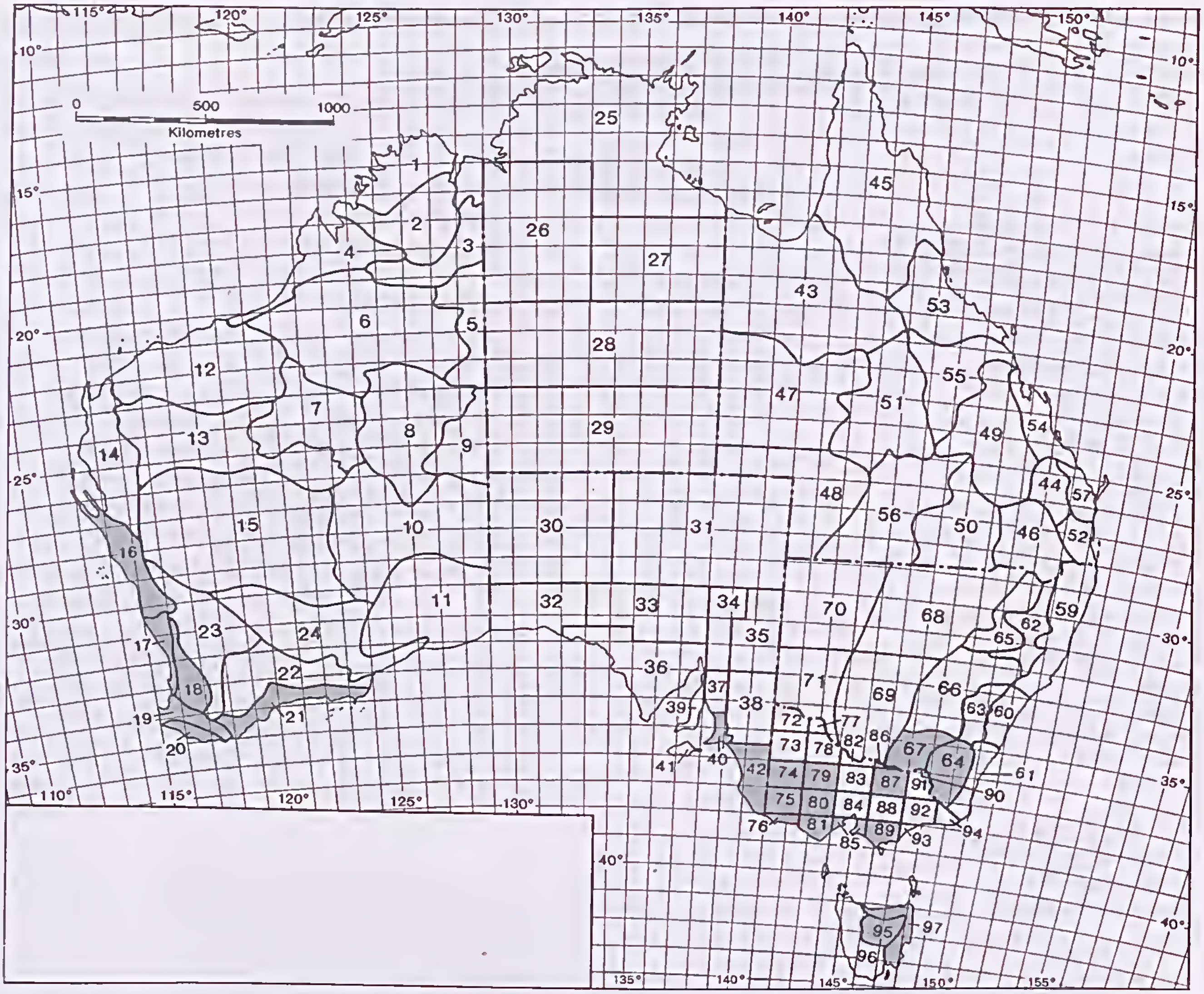

Fig. 3. The Australian botanical subdivisions (shaded) in which *Isoetes drummondii* A.Braun has been recorded (boundaries after Hnatiuk 1990).

Benson & Howell (1990) propose that at the time of European settlement, the higher terraces were covered by woodlands dominated by *Eucalyptus moluccana* (Grey Box) and *Eucalyptus tereticornis* (Forest Red Gum) with an open grassy understorey. Mangroves, (*Avicennia marina*) and samphires (Chenopodiaceae) are likely to have colonised the river margins below the tidal limit (approximately below Charles Street) while *Phragmites australis* (Common Reed) and *Melaleuca linariifolia* (paperbark), and *Angophora floribunda* (Rough-barked Apple) occupied wetter and drier areas on the river terraces respectively. Clearing and cultivation of the higher river terraces at Parramatta was carried out by convict gangs between 1789 and 1791, and the first crops including wheat, barley, oats and maize, were planted on ground broken up by hoe and fertilised by the ashes of burnt native vegetation.

Excavation results (Casey & Lowe 2004) confirm that the George and Charles Streets archaeological site, which is about 5 m above present day river level, was part of town leases occupied by five wattle-and-daub 'convict huts' by c. 1790. By c. 1809 the five properties were leased by emancipated convict and free settlers. In 1823, all Parramatta residents 'who could show no better claim to the portions they now occupy than mere sufferance [were invited to] apply for [21 year] leases' (Jervis 1961, p26) and a contemporary plan (Fig. 5) shows the archaeological site had been formally subdivided and occupied by diverse tenants although none of the six allotments are known to have been used for the agistment of stock from southern New South Wales. Subsequent residents appear to have occupied the early dwellings until at least the 1830s. By the mid 1850s, Lots 69, 70 and 72 were owned by William Brynes, a successful entrepreneur who built and occupied a large house and other commercial premises on the corner of George and Charles Streets. The Byrnes family controlled these three properties into the early 20th century and presumably used the area at the rear (river-side) for accommodating the various pets whose remains were uncovered during the excavation:

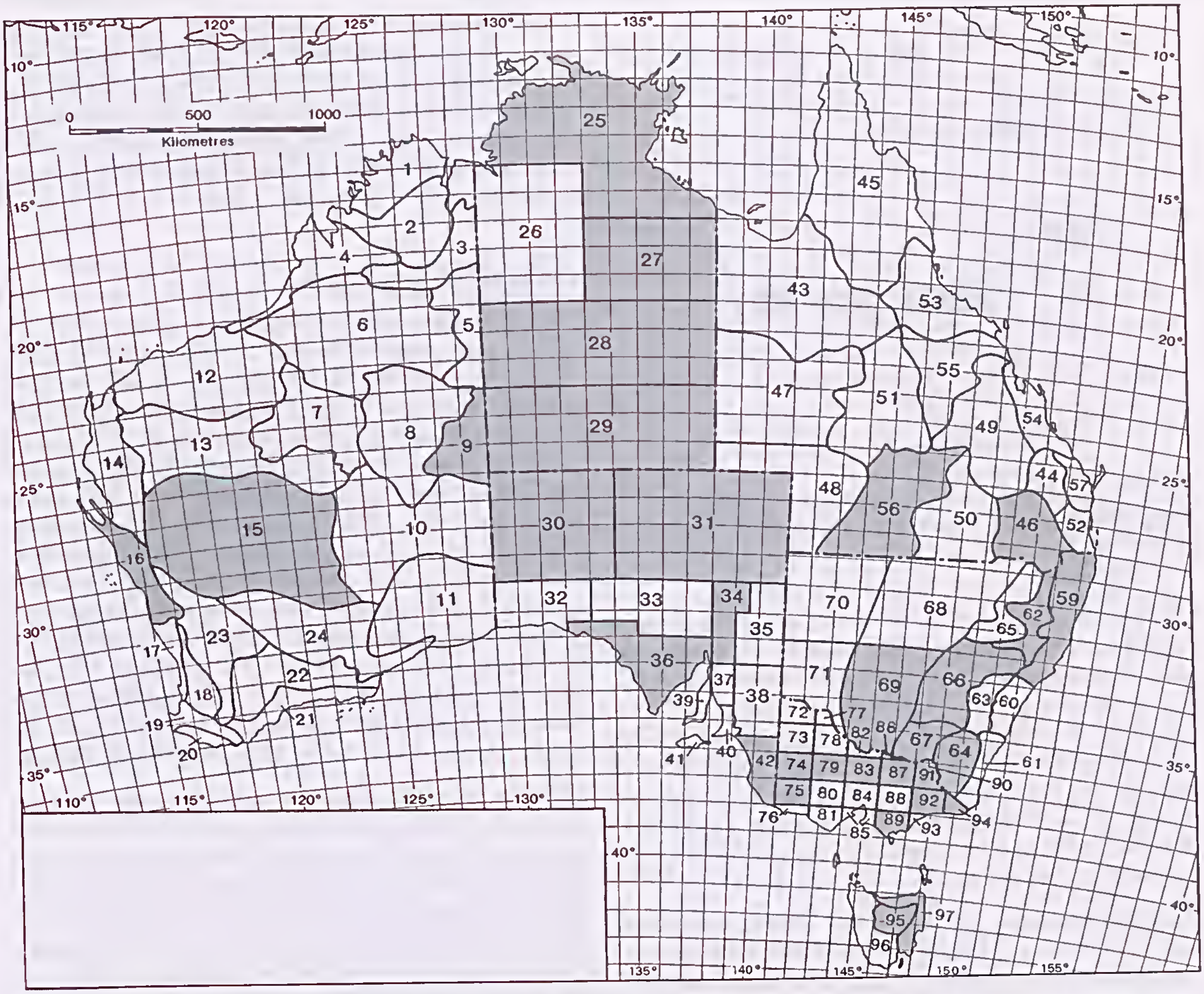

Fig. 4. The Australian botanical subdivisions (shaded) in which *Isoetes muelleri* A. Braun has been recorded (boundaries after Hnatiuk 1990).

a pony, a horse, a dog, two calves and possibly other animals. Lot 69 and part of Lot 70 were subsequent leased to a Chinese market gardener, Ah Chee, between 1905 and the 1930s. Two warehouses occupied the same property by the 1960s.

Fossil *Isoetes* microspores

Fossil *Isoetes*-type spores were recovered from buried deposits on Lots 69 and 70, which backed onto the c. 2 m high escarpment leading down to the present-day floodplain of the Parramatta River, and Lot 72, which fronted onto George Street (Fig. 5, Appendix 1). In all instances the sediments appear to be redeposited alluvium (R. Lawrie pers. comm.) that had undergone varying degrees of modification since 1788. For example, one of the two deposits preserving *Isoetes drummondii*-type spores on Lot 69 (ACN 2425) included whole and fragmented bricks, oyster shells, and fishbones and scales; the sample preserving *Isoetes muelleri*-type spores from Lot 70 (ACN 2202) comes from a section that had been heavily modified by market gardening and other 20th century activities. In contrast, *Isoetes* cf. *muelleri* spores found on Lot 72 (ACN 2791) were preserved in an essentially unmodified silty sand used as packing around a post that may have been part of a 1790s convict hut.

Many of the microspores are partially disrupted or unfavourably orientated, but sufficiently well-preserved/orientated specimens were found to determine their affinity using reference microspores recovered from herbarium specimens of commonly occurring *Isoetes* species in southeastern Australia (Plate 1, Figs A–K).

Age

The presence of pollen from introduced taxa, in particular pine (Pinaceae), and widely naturalised weeds such as cereals (Poaceae pollen > 60 µm in minimum diameter), dandelions (Asteraceae: Liguliflorae) and plantain

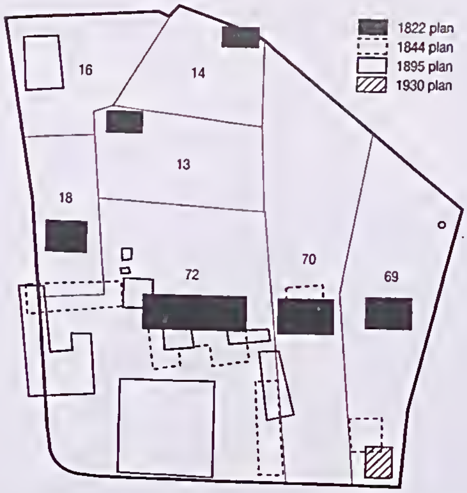

Fig. 5. The George and Charles St Parramatta site showing subdivision of into allotments in 1822 and location of buildings on the site up to 1890.

(*Plantago lanceolata*-type) are routinely used to distinguish sediments accumulating before and since European settlement (Macphail 1999). In some instances, a more precise age can be inferred if planting times have been recorded. The minimum age of the samples is less easily inferred because of the longevity (and replanting) of exotic trees such as pines (*Pinus* spp.) and oaks (*Quercus* spp.), and also because short-lived exotic herbs such as cereals and dandelions became widely naturalised during the late 18th and early 19th centuries.

A necessary condition is that the exotic pollen accumulated at the same time as the deposit in which they are preserved (in situ occurrences). Although this can be demonstrated for some soils buried to depths of 30 cm or less on some historical archaeological sites (Macphail 1999), several factors at the George and Charles Streets archaeological site make it likely that some pollen and spores have infiltrated the soil profile in rainwater or down cicada burrows. These factors include the high porosity/permeability of the A_1 and A_2 horizons, the high degree of bioturbation and the presence of illuvial clay laminae in the B horizon. Tillage and trampling by stock can also lead to the incorporation of younger material into older sediments. For example, all assemblages (Table 1) include low to frequent numbers of Liguliflorae pollen that are identical to those produced by the European dandelion, *Taraxacum officinale* and other introduced species such as the Common Sowthistle, *Sonchus oleraceus* L. A native source is considered improbable since the nearest species producing a similar pollen morphotype, *Microseris scapigera* (Walp.) Schultz-Bip and *Sonchus hydrophilus* Boulos, are mostly restricted to high elevations on the Blue Mountains west of the Cumberland Plain.

Liguliflorae, and other definite exotic pollen types such as Pinaceae (Table 1), support the archaeological data that the alluvium preserving fossil *Isoetes* microspores on Lots 69 and 72 have accumulated sometime between 1790 and the 1830s. The modified soil represented by ACN 2202 on Lot 70 is likely to be younger than c. 1830, or may be contaminated with younger material, based on (a) the low relative abundance of *Eucalyptus* and *Allocasuarina/Casuarina* pollen relative to other samples and (b) the significant representation of exotic pine and fruit tree (*Malus*-type) pollen.

Discussion & conclusions

Isoetes is the only widespread surviving genus of a geologically ancient order of heterosporous fern allies (Isoetales) whose origins lie in the shrub- and tree-sized lycopods forming the first terrestrial forests in the Devonian. A review of the palynological literature indicates fossil *Isoetes* microspores have not been recovered from any Australian Neogene sediment and are extremely rare in Holocene or earlier Quaternary deposits outside of southern Tasmania (see Macphail 1979). Although many mainland Quaternary sequences are situated within the modern range of *Isoetes*, the only known records of its microspores comes from earliest Pleistocene deposits near Daylesford, central Victoria (K. Sneiderman pers comm.), and Holocene estuarine sediments in Wilson Inlet, Denmark in southwest Western Australia (Macphail 1998). A not unlikely explanation is that *Isoetes* microspores have been overlooked or misidentified.

All living *Isoetes* possess leaves that superficially resemble low sedges or grasses, and are easily overlooked in botanical surveys (cf. Duncan & Isaac 1986). Nevertheless the absence of *Isoetes* on the Central Coast and Central Tablelands of New South Wales is difficult to explain, given the wide distribution and broad climatic tolerance of the genus within Australia. For example, *Isoetes muelleri* ranges from subalpine and alpine lakes in Tasmania to semi-permanent soaks and ephemeral pools in arid Central Australia, including on the top of Uluru/Ayres Rock, and in dune swales in the Simpson Desert (Jessup 1981, Hnatiuk 1990, Chinnock 1998).

The absence of archaeological and documentary evidence for natural or artificial ponds makes it highly unlikely that *Isoetes* had been deliberately introduced onto any of the three Parramatta allotments by stock. Conversely the documentary and fossil pollen evidence provides strong circumstantial evidence that *Isoetes* microspores could have been carried up in domestic water from ponds on the lower floodplain of the Parramatta River, between 1790 and 1840. The same deposits preserve spores of liverworts (form genera *Cingulatisporites*, *Rudolphisporis*) and mesophytic ferns (*Calochlaena*, *Pteris*, unidentified monolete and trilete species) as well as pollen of semi-aquatic (Cyperaceae, *Lemna*), and saltwater-tolerant (Chenopodiaceae) herbs.

If correctly interpreted, the microfossil data from the Parramatta and Richmond archaeological sites demonstrate that two or possibly more species of *Isoetes* were growing in wet habitats on the Cumberland Plain in the early Colonial period. If so occurrences were probably relatively rare.

The botanist Robert Brown collected extensively on the Hawkesbury and Grose Rivers in 1802–5, but did not record *Isoetes*, although he recorded the aquatic fern *Azolla*, which might be expected to occupy similar habitats to *Isoetes*. Nor does Bentham indicate any records of *Isoetes* in New South Wales in his *Flora Australiensis* in 1878 (D. Benson pers. com).

The corollary that European activities were responsible for their subsequent local extinction seems unavoidable. Intensive grazing may have been a factor since *Isoetes drummondii* subsp. *drummondii* is recorded as being palatable to introduced stock and native animals in Tasmania (see Chinnock 1998). Against this, the abundance of domestic waste in the Richmond waterhole shows that the *Isoetes* population was clearly tolerant of moderate levels of disturbance and pollution. Hence we speculate that that *Isoetes* may still survive in long-protected remnant wetlands on the Cumberland Plain. On the wider scale, the presence of *Isoetes* in the Central Coast botanical subdivision 'bridges' the biogeographic gap between populations on the Southern Tablelands and Central-Western and South-Western Slopes, and those on the North Coast and Northern Tablelands botanical subdivisions. We conclude therefore that the disjunct distribution of *Isoetes* in New South Wales also is likely to reflect European activities.

Note Added In Proof

Since this paper was prepared, *Isoetes drummondii*-type microspores have been found at a site at 95–101 George St., Parramatta in contexts that can be securely dated by the associated archaeological evidence (W. Thorpe pers. comm.). These are (1) a well-preserved specimen in soil infilling a hoe mark in a c. 1790–1800s orchard [ACN 791] and (b) a poorly-preserved specimen in organic-rich silts infilling an 1830s waterhole [ACN 1037].

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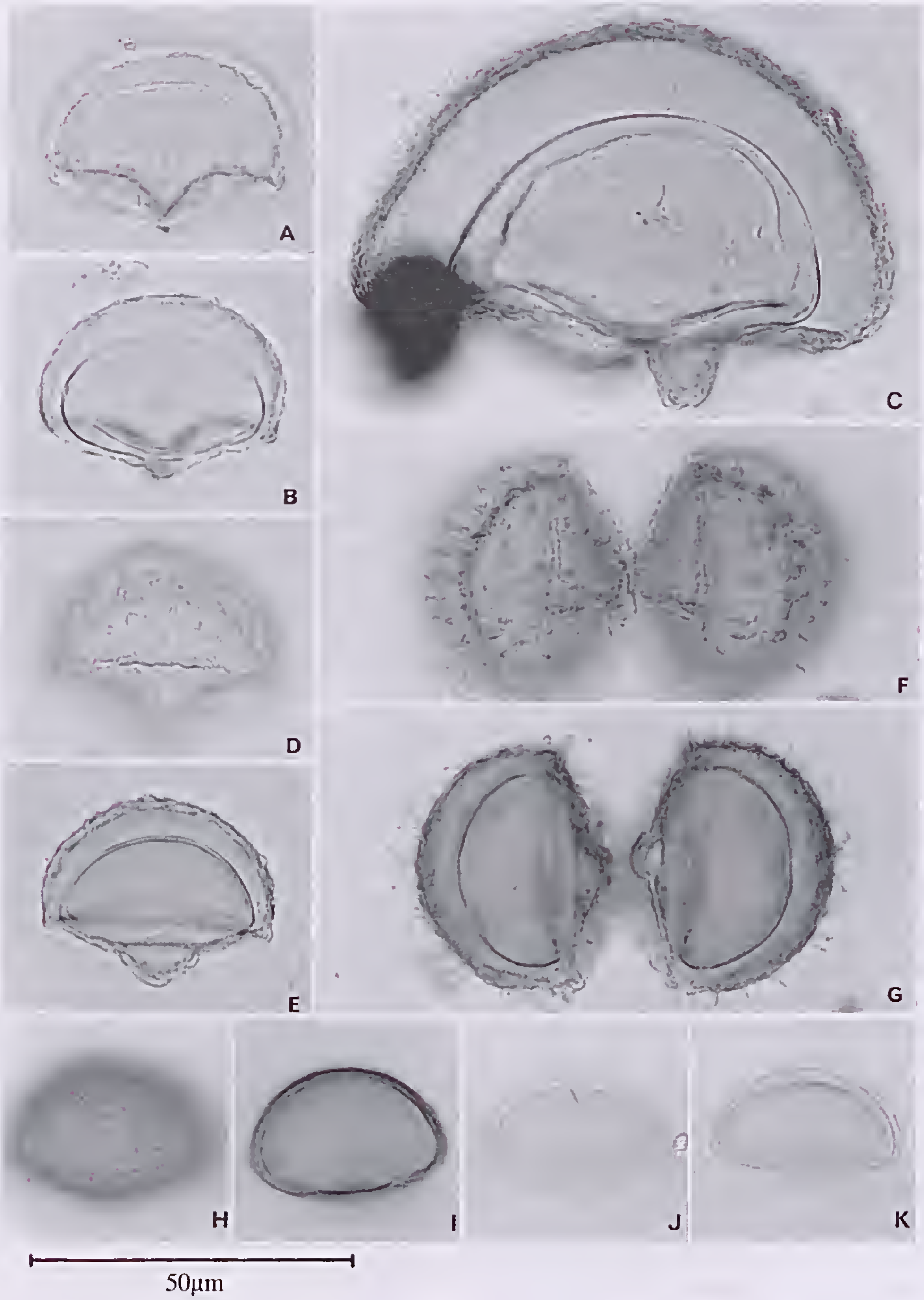

Plate 1: Microspores of living *Isoetes* species

All photomicrographs taken at x788 magnification (50 µm scale bar). Specimens are mounted in glycerol jelly unless otherwise noted. **Figs A–B.** *Isoetes drummondii* A.Braun subsp. *anomala* C.R.Marsden & Chinnock. Microspores in surface (Fig. A) and median (Fig. B) optical section showing laminated perine and weakly-developed 'keel'. Cultivated plant, Royal Botanic Gardens, Sydney. NSW629437. **Fig. C.** *Isoetes elatior* F.Muell. Microspore in median optical section showing laminated perine and well-developed 'keel'. Specimen collected by W.H. Archer. Locality and date not recorded on herbarium sheet but probably from Lake River, Longford, Tasmania, circa 1910). **Figs D–E.** *Isoetes pusilla* C.R.Marsden & Chinnock. Microspores in surface (Fig. D) and median (Fig. E) optical section showing shallow verrucate perine and well-developed 'keel'. Specimen collected from near Chiltern, Victoria, by H.B. Williamson, November 1910. NSW629447. **Figs F–G.** *Isoetes muelleri* A.Braun. Pair of attached microspores showing echinate perine and well-developed 'keel'. Cultivated plant, Royal Botanic Gardens, Sydney. NSW492905. **Figs H–I.** *Isoetes gunnii* R.Br. Microspores in surface (Fig. H) and median (Fig. I) optical section showing finely scabrate perine and weakly-developed 'keel'. Specimen (mounted in silicon oil) collected from Pine Lagoon, central Tasmania by D.J. Morris, 25 April 1974. HO 444280. **Figs J–K.** *Isoetes humilior* F.Muell. Microspores in surface (Fig. H) and median (Fig. I) optical section showing psilate perine and weakly developed, ± hyaline 'keel'. Specimen (mounted in silicon oil) collected from the entrance to Little Pine Lagoon, central Tasmania 17 January 1991 (collector not recorded on herbarium sheet). HO 142945.

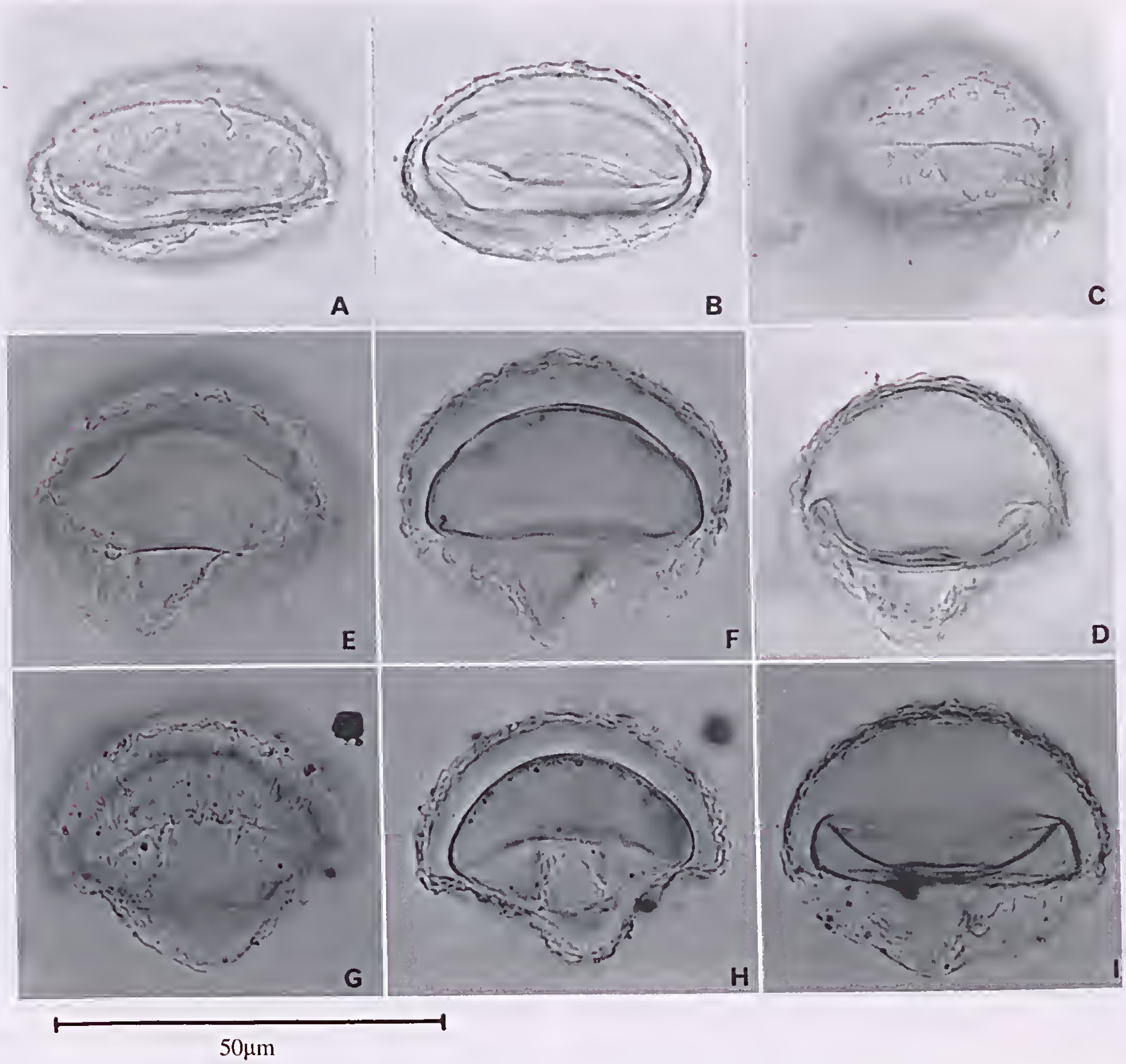

Plate 2: Fossil microspores assigned to *Isoetes drummondii* subsp. *anomala*-type

All photomicrographs taken at x788 magnification (50 µm scale bar) **Figs A–B.** Microspore in oblique surface (Fig. A) and median (Fig. B) optical sections section showing laminated/verrucate perine and well-developed 'keel'. George and Charles Streets Parramatta archaeological site: Lot 69 Area 15 ACN 2430. **Figs C–D.** Microspore in surface (Fig. C) and median (Fig. D) optical sections section showing laminated/verrucate perine and well-developed 'keel'. George and Charles Streets Parramatta archaeological site: Lot 69 Area 15 ACN 2425. **Figs E–F.** Microspore in surface (Figs E) and median (Fig. F) optical sections section showing laminated/verrucate perine and well-developed 'keel'. 1.20 m depth below ground surface. Richmond archaeological site. **Figs G–I.** Microspores in median optical sections section showing laminated/verrucate perine and well-developed 'keel'. 1.00 m depth below ground surface. Richmond archaeological site.

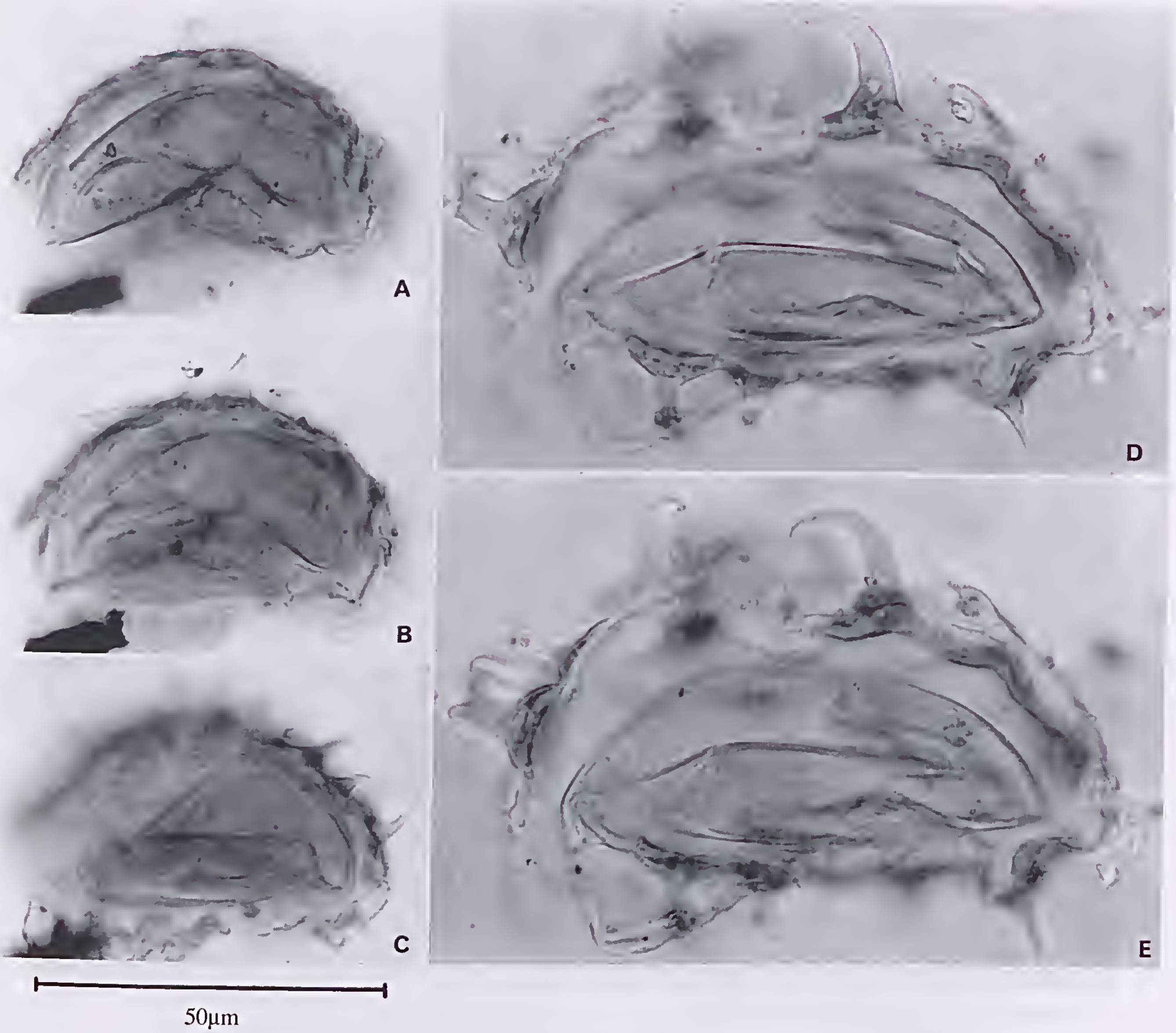

Plate 3: Fossil microspores assigned to *Isoetes muelleri*-type

All photomicrographs taken at x788 magnification (50 µm scale bar) **Figs A–C.** Relatively small microspore in oblique surface (Fig. A) and median (Figs B, C) optical sections showing echinate perine. George and Charles Streets Parramatta archaeological site: Lot 70 Area 15 ACN 2202. **Figs D–E.** Large microspore in median optical section showing robustly echinate perine. George and Charles Streets Parramatta archaeological site: Lot 72 Area 13 ACN 2791.

Appendix 1

Description of fossil *Isoetes* microspores from Parramatta

Isoetes drummondii-type (Plate 2, Figs A–I).

Description — Microspores are monads, heteropolar bilateral, monolete; laesura obscure but probably long and straight on the protruding (proximal) face; amb elliptical in polar view, biconvex in equatorial view; cell wall consisting of inner (exine) and outer (perine) layers which may become separated during the fossilisation process; exine thin, < 0.8 µm, ±hyaline; perine relatively thick ~1.6 µm, optically dense (laminated?), sinuous with scabrate-verrucate sculptural elements; Maximum measurement 33–36 x 36–42 µm (4 specimens).

Fossil distribution — George and Charles Streets Parramatta archaeological site: Lot 69 Area 15 ACN 2425 (2%) & ACN 2430 (4%), Area 16 ACN 2484 (trace). Richmond archaeological site: Samples 4 to 11 (2–45%).

Comment — Perine ornamentation in microspores of *Isoetes drummondii* A.Braun subsp. *anomala* C.R.Marsden & Chinnock varies from shallow indistinctly formed rugulae (Plate 1, Figs A–B) to well-developed verrucae which occasionally expand into longer protrusions. The fossil microspores recovered from the Parramatta and Richmond archaeological sites closely resemble the latter morphotype in that (i) the 'laminated' perispore is distinctly ornamented with irregularly distributed, low verrucae that occasionally expand into longer protrusions and (ii) the perispore 'keel' is well developed. The Victorian endemic species *Isoetes pusilla* C.R.Marsden & Chinnock produces ± identical microspores (Plate 1, Figs D–E) and this also is likely to case with microspores produced by *I. drummondii* subsp. *drummondii* C.R.Marsden & Chinnock. The perispore in the other *Isoetes* species found in Victoria and/or Tasmania, viz. *I. elatior* F.Meull. ex A.Braun (Plate 1, Fig. C), *I. gunnii* A.Braun (Plate 1 Fig. H–I) and *I. humilior* F.Muell. ex A.Braun (Plate 1, Fig. J–K) lack well-defined sculptural projections as do the Western Australian endemics *I. inflata* E.R.L.Johson, *I. mongerensis* E.R.L. Johnson and *I. tripus* A.Braun (see Chinnock 1998): Whether the perine of microspores produced by *Isoetes coromandelina* L. f. subsp. *macrotuberculata* C.R.Marsden, and *I. cristata* C.R.Marsden & Chinnock is ornamented is unknown (see Johnson 1984, Chinnock 1998).

Isoetes muelleri-type (Plate 3, Figs A–C).

Description — Microspores are monads, heteropolar, bilateral, monolete; laesura obscure but assumed to be long and straight on the protruding (proximal) face; amb elliptical in polar view, biconvex in equatorial view; cell wall consisting of inner (exine) and outer (perine) layers which may become separated during the fossilisation process; exine thin, < 0.8 µm, ± hyaline; perine thick ~2.5 µm, optically dense, surmounted by scattered, recurved (thorn-like) echini to 12 µm long with bases ~4 µm wide. Maximum measurements 38 x 56 µm (1 specimen).

Fossil distribution — George and Charles Streets Parramatta archaeological site: Lot 70 Area 15 ACN 2202 (trace).

Comment — The species is distinguished from *Isoetes drummondii* subsp. *anomala* and other Australian species for which reference material is available, by short to long thorn-like protrusions (echini) on the perine. Some of the taller sculptural elements appear to be solid whilst others appear to be vacuolate and more strap-like in bright field optical section. Other *Isoetes* species described by Chinnock (1998) as producing spinulose to spinose or baculate/digitate microspores are endemic to Western Australia (*I. australis* R.S.Williams, *I. caroli* E.R.L.Johnson) and southeastern South Australia (*I. attenuata* C.R.Marsden & Chinnock)

Isoetes sp. cf. *I. muelleri* A. Braun (Plate 3, Figs D–E).

Description — Microspores are monads, heteropolar, bilateral, monolete; laesura obscure but assumed to be long and straight on the protruding (proximal) face; amb elliptical in polar view, biconvex in equatorial view; cell wall cell consisting of inner (exine) and outer (perine) layers which may become separated during the fossilisation process; exine thin, < 0.8 µm, ± hyaline; perine thick ~3.5 µm, surmounted by scattered recurved (thorn-like) echini to 16 µm long on bases to 8 µm wide; Maximum measurements 64x105 µm (1 specimen).

Fossil distribution — George and Charles Streets Parramatta archaeological site: Lot 72 Area 13 ACN 2791 (1%).

Comment — The species is distinguished from reference specimens of *Isoetes muelleri* A.Braun by its much larger size (106 µm vs 56 µm) and the robust ornamentation. Vacuoles occur within the bases of the larger echini. Whether the morphotype represents a different species or is a large (polyploid?) variant of *Isoetes muelleri* is unknown.

Range extension, habitat and conservation status of three rare mallees, *Eucalyptus castrensis*, *Eucalyptus fracta* and *Eucalyptus pumila* from the Hunter Valley, NSW

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Abstract: New populations of three threatened mallee species, *Eucalyptus castrensis* K.D.Hill, *Eucalyptus fracta* K.D.Hill and *Eucalyptus pumila* Cambage (all Myrtaceae), have recently been found in the Singleton Military Area in the Hunter Valley of New South Wales (32°45'S, 151°15'E). Each population is significant as they increase the known distribution and total numbers of three highly restricted species. Details of the habitat and size of each additional population are given and conservation notes provided.

Cunninghamia (2005) 9(2): 307–309

Introduction

The Singleton Military Area (SMA) covers about 14 375 ha in the central Hunter Valley of New South Wales, 20 km south of Singleton (32°45'S, 151°15'E; Fig. 1). It is bisected west to east by the Broke-Cessnock road. North of this road the SMA has been largely cleared and is gently undulating while to the south the terrain is relatively steep and corresponds to the northern fall of the Broken Back Range. The geology is fine-grained sandstones of the Early Permian and Triassic periods which are part of the Hunter Valley Dome Belt (Herbert & Helby 1980). Altitudes range from 40 m ASL in the far north of the SMA to over 500 m on top of the Broken Back Range.

During 2004 field surveys targeting rare or threatened vascular plant species and endangered ecological communities were conducted in the SMA to provide the Department of Defence with management guidelines to minimise impacts on these taxa and communities, and to secure their future. Considerable effort was made to determine the distribution of each rare species, their population sizes and their potential threatening processes over two survey periods (June and December 2004). Nine rare or threatened plant species and one endangered community were found within the SMA (Hunter 2004). Of particular interest were the discoveries of several new populations of three rare mallees: *Eucalyptus castrensis* K.D.Hill, *Eucalyptus fracta* K.D.Hill and *Eucalyptus pumila* Cambage (all in family Myrtaceae). These mallee species, although not closely related, are all endemic to the same limited area and are of high conservation significance. Prior to this study each species was known from just a single population. This paper describes the size, habitat, fire response and potential threats for these recently discovered populations.

Species profiles

Eucalyptus castrensis

This species has a typical mallee habit and grows to a height of 8 m (Hill & Stanberg 2002). It appears to be most similar to *Eucalyptus aenea* K.D.Hill to which it differs by its larger buds, fruit and adult leaves, and by retaining a small amount of rough bark at the base of larger adults (Hill & Stanberg 2002). *Eucalyptus aenea* itself is a narrow endemic found 100 km to the north-west in Goulburn River National Park and Manobalai Nature Reserve (Hill 1997, 2002; Bell 2001; Peake 2005).

When described by Hill & Stanberg, *Eucalyptus castrensis* was only known from a single stand approximately 3 hectares in size, and was considered endemic to the SMA (*castra* meaning camp in reference to the SMA). Our survey of this population estimated it to contain between 27–37 000 individuals and cover an area of approximately 10 hectares. This population estimate was made by counting the number of individuals within two 100 x 10 m belt transects and then extrapolating across the occupancy area (Hunter 2004). The high number of individuals is not surprising considering the species was uniformly mono-dominant throughout the stand.

In addition to the type location, a number of additional populations of *Eucalyptus castrensis* were found within the SMA during the recent surveys. The five new populations ranged from a single plant to approximately 150 individuals. The western most stand was approximately 2 km west of the type population and the southern most stand was just 150 m north of the boundary with Pokolbin State Forest.

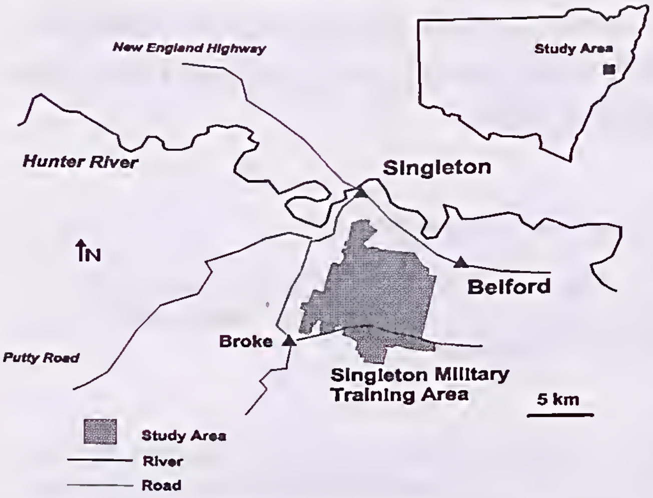

Fig. 1. The location of the Singleton Military Area on the lower North Coast of New South Wales.

The newly discovered stands occurred on relatively flat benches on top of northerly running spurs. The soil on these sandstone benches was particularly shallow with small patches of exposed rock often outcropping at the surface. The dominant tree species in the surrounding area were usually *Eucalyptus fibrosa*, *Corymbia maculata* and (less commonly) *Callitris endlicheri*. Each population of *Eucalyptus castrensis* however, formed a tightly packed stand rarely with space for other tree species within them. Shrub species such as *Bursaria spinosa*, *Dodonaea viscosa* subsp. *angustifolia*, *Olearia elliptica* s.l., *Phyllanthus virgatus* and *Pultenaea spinosa* were often growing within the stands along with a sparse ground layer of *Cheilanthes sieberi* subsp. *sieberi*, *Eragrostis brownii*, *Themeda australis*, *Desmodium varians* and *Paspalidium gracile*. All populations of *Eucalyptus castrensis* had been recently burnt in a wildfire event approximately 18 months prior to the first survey (i.e. burnt early 2003). Despite the severity of the fire, however, only the periphery of the type population was burned leaving the centre unburnt. All other smaller stands were severely affected although a few unburnt individuals were observed in the rockier, open areas. All burnt individuals were resprouting from their lignotubers with the thick regrowth attaining a height of 1–2 metres in 2004.

Hill & Stanberg (2002) suggested a ROTAP code of 2V for *Eucalyptus castrensis* following the criteria of Briggs & Leigh (1996). The species has also recently been listed on Schedule 1 (Endangered) of the *NSW Threatened Species Conservation Act 1995*. Despite the discovery of several additional satellite populations, and the total number of plants likely to exceed 30 000 individuals, we still consider that the species may be under some threat. The highly restricted distribution of *Eucalyptus castrensis* (confined to 4 km^2), and the likely occurrence of frequent fires, suggest that the status of vulnerable is the most appropriate.

Eucalyptus fracta

This spreading mallee or small tree can reach a height of 10 m (Hill 1997). It is thought to be most closely related to *Eucalyptus sideroploia* Benth. but differs by its smaller habit, more rounded juvenile leaves, broader fruits and smaller buds (Hill 1997). *Eucalyptus sideroploia* also tends to be a forest species growing in deeper, more fertile soils in protected sites.

When described by Hill (1997), *Eucalyptus fracta* was known from just a single population at the far northern extremity of the Broken Back Range. Our recent survey of this locality revealed that the population extends for approximately 1.5 km east-west along the northern side of a narrow ridge (Hunter 2004). Soils were particularly shallow (occasionally skeletal) and a dry, exposed northerly aspect was favoured. The population was estimated to be at least 1000 individuals and occupied both Pokolbin State Forest and a small area of the SMA. The fire in early 2003 was particularly severe at this site and virtually all individuals of *Eucalyptus fracta* were burnt. In December 2004 most individuals were vigorously resprouting however, and a few of the resprouting plants were beginning to flower.

A second population of about 300 individuals of *Eucalyptus fracta* was also discovered on the ridge immediately south of the type population. These plants occupied the same habitat as the type location and were associated with the same tree species (*Corymbia maculata*, *Eucalyptus punctata* and *Angophora euryphylla*). This population appeared to have been less severely burnt and at least 30 mature individuals escaped damage. These plants were up to 10 m tall and were typically single-stemmed trees rather than mallees. The majority of the population was within the SMA with a few individuals in the adjacent Pokolbin State Forest.

All currently known individuals of *Eucalyptus fracta* occur in a State Forest or a Commonwealth owned military training area, neither of which meet the criteria of a conservation reserve (Briggs & Leigh 1996). In addition, the small size of the total population (currently thought to be less than 1500), and the continuing threat from frequent wildfires, suggest that a ROTAP code of 2V may be more appropriate than the 2R proposed by Hill (1997). The species is currently listed on Schedule 2 (Vulnerable) of the *NSW Threatened Species Conservation Act 1995* and we support this listing.

Eucalyptus pumila

This small mallee reaches a height of about 6 m (Brooker & Kleinig 1999) and is the sole representative of *Eucalyptus* section *Pumilio* (Brooker 2000). As such it is a distinctive species with no close relatives and is of particular phylogenetic conservation significance. Since its description nearly 100 years ago (Cambage 1919), it has only been known from the type population in Pokolbin Flora Reserve and an adjacent private property.

During the 2004 rare plant surveys two additional populations were discovered in the SMA (Hunter 2004), approximately 4 km north-west of the type locality and separated from each other by just 300 m. Despite their close proximity these populations are quite distinct, occuping very similar habitats (flat benches on a steep-sided spur) but separated by a deep valley. Soils were shallow and rocky with the benches exposed to the north. Vegetation of the surrounding area was woodland dominated by *Eucalyptus fibrosa* and *Corymbia maculata* although these species never entered the dense mallee stands. Associated shrubs included *Persoonia linearis, Exocarpos cupressiformis, Leptospermum parvifolium* and *Olearia elliptica* s.l. while a sparse ground layer of *Paspalidium gracile, Platysace ericoides* and *Pomax umbellata* was present in both populations. At one of the *Eucalyptus pumila* stands, *Eucalyptus castrensis* occurred sympatrically, an association not known to occur elsewhere. Both populations of *Eucalyptus pumila* were severely burned in early 2003 although a few mature individuals escaped the fire and were flowering profusely during the June 2004 survey. Previously, the species has only been reported as flowering in April-May (Brooker & Kleinig 1999). All burnt plants were resprouting and the new growth was typically up to 1.5 m tall. Approximately 150 plants were present in each population, although these estimates were difficult to make due to the tightly-packed nature of the individuals and the dense regrowth.

Despite the additional populations, the conservation code of 2VCi (Briggs & Leigh 1996) and the current listing of the species as Vulnerable on the *NSW Threatened Species Conservation Act 1995* is still considered appropriate. All known plants of *Eucalyptus pumila* occur within 5–6 km of each other and this highly restricted distribution leaves them vulnerable to threats such as an inappropriate fire regime.

Discussion

The recently discovered populations of *Eucalyptus castrensis, Eucalyptus fracta* and *Eucalyptus pumila* are all of significance given the highly restricted distributions and relatively low population numbers of each species. Only the type population of *Eucalyptus pumila* in Pokolbin Flora Reserve is currently reserved. The Department of Defence, which controls the SMA, has made a commitment to protect all rare or threatened plants and endangered ecological communities within the SMA. The Department is aware of each of the new *Eucalyptus* populations and is willing to manage all populations effectively to ensure their continued survival. Potentially destructive activities within the vicinity of known populations will be excluded. This is an important step as the SMA is of considerable environmental significance (Peake 2005), particularly when one considers the three quite unrelated eucalypts that share the habitat within the same small geographic area. The northern fall of the Broken Back Range should be considered a significant region of endemism for *Eucalyptus* following the criteria of Platnick (1991). As all recently discovered populations occupied similar habitats (shallow, rocky ridges with a northerly aspect), it is possible that further stands may be found in nearby areas of similar habitat that still remain botanically unexplored.

Acknowledgements

The Department of Defence instigated the project, funded the fieldwork and allowed full access to all of the SMA. We would especially like to thank Louise Cairns of this department for logistical support, assistance in the field and for comments on the manuscript. Stephen Bell and Vanessa Hunter also gave valuable assistance in the field with Stephen also providing useful feedback on the manuscript. Travis Peake and an anonymous referee are thanked for further improvements to the paper.

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Rediscovery of Ooline, *Cadellia pentastylis,* near Gunnedah: notes on the habitat and ecology of this dry rainforest tree

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Abstract: *Cadellia pentastylis* F.Muell., (family Surianaceae), a dry rainforest tree with a conservation listing of Vulnerable at state and national levels, was first collected from the Gunnedah area by the botanical collector J.L. Boorman in 1907. We report the first record of *Cadellia pentastylis* from the Gunnedah area (30°58′49″S, 150°15′15″E) since 1907, and provide details of the community and habitat where it occurs, on the lower slopes of Black Jack Mountain. Although this population is one of the smallest in New South Wales, it is significant as it is at its southern distributional limit, and is found adjacent to semi-evergreen vine thicket, another type of dry rainforest, on the same hillslope. We list the New South Wales occurrences of this species and discuss aspects of its flowering phenology.

Cunninghamia **(2005) 9(2): 311–316**

Introduction

Botanical exploration is replete with tales of rediscovery of species or populations thought to be lost from an area; e.g. the rediscovery of the cool-temperate rainforest species *Nothofagus moorei* on the Comboyne Plateau (Bale & Williams 1994) or the suspected demise and subsequent rediscovery of *Hakea pulvinifera*, an extremely rare species known only from a single hillside near Lake Keepit east of Gunnedah (Leigh et al. 1984; Barker & Morrison 1989). In 1994, Bob Howarth of Gunnedah brought samples of a 'red-flowered' tree collected on Black Jack Mountain, south-west of Gunnedah to one of us (SRC). At the time, the samples could not be identified, but several years later SRC recognized the line drawing on the cover of Benson's (1993) Ooline Species Management Plan as resembling Howarth's specimen. No reference could be found to *Cadellia pentastylis* F.Muell. having red petals or sepals (Beadle 1984 cited in Benson 1993; Harden 1991) and the matter was taken no further.

In November 2004, *Cadellia pentastylis* flowered extensively in the Narrabri district (James Faris & Geoff Robertson, pers. comm.). Specimens and photographs of the early stages of fruit development showed that the petals had fallen with the light brown to red coloured sepals persisting. When shown specimens in fruit, Bob Howarth confirmed that they were similar to those that he had seen in 1994, and showed TJC the locality of the plants now confirmed as *Cadellia pentastylis*.

This was not the first record of *Cadellia pentastylis* from the Gunnedah area. In 1907, the botanical collector John Lucas Boorman lodged a sterile specimen at the National Herbarium of NSW (NSW 362008) but there are few details to accompany this specimen and the locality referred simply to "Gunnedah" (Peter Hind pers. comm. 2005). The species has not been recorded in the locality since but given the scant location details provided by Boorman, it is not possible to determine if the population he collected from is the same one reported here.

Cadellia pentastylis is a medium to large tree, known colloquially as 'Ooline' or 'Scrub Myrtle' (Benson 1993). It is the only member of its genus (Harden 2002) and is placed in a family, Surianaceae, which has only four genera (of which three are monotypic) and five species (Ian Telford pers. comm.). *Cadellia pentastylis* is of rainforest origin (Benson 1993) and its putative closest living relative, *Guilfoylia monostylis*, is a shrub or small tree found in several rainforest types on the east coast of Australia.

Cadellia pentastylis is endemic to the North Western Slopes of NSW and southern and central Queensland south from near Emerald (Gwen Harden pers. comm.). Since European settlement, much of the natural habitat of *Cadellia pentastylis* has been cleared for cropping or grazing (Benson 1993). It is now listed as a Vulnerable species under the NSW *Threatened Species Conservation* (TSC) *Act 1995* and under the Commonwealth *Environment Protection and Biodiversity Act 1999*. Furthermore, the *Cadellia pentastylis* community is listed as an Endangered Ecological Community in NSW under the TSC Act.

In this paper we describe the vegetation and habitat of the *Cadellia pentastylis* population on Black Jack Mountain, and relate the timing of flowering to rainfall records from Gunnedah.

Methods

Survey work on Black Jack Mountain was conducted in December 2004 and January 2005 to describe the environment and vegetation associated with *Cadellia pentastylis*. The boundaries of the *Cadellia pentastylis* population were recorded with a global positioning system. A species list was compiled from foot traverses through the two stands and from data collected for a 20 m x 20 m floristic plot undertaken as part of a larger survey of dry rainforest. The density of *Cadellia pentastylis* was estimated by recording the number of individuals from three different size classes (large tree - diameter at breast height (DBH) > 10 cm; small tree — DBH < 10 cm; seedling < 50 cm height) in each of four 20 m x 20 m plots in the eastern stand which were located to sample the range of densities. Benson (1993) noted the ability of *Cadellia pentastylis* to coppice, and this presents problems in estimating the number of individuals. For our density counts we recorded any separate stem that was not obviously attached to another stem as a separate individual. Specimens of *Cadellia pentastylis* were collected (*TJ Curran 201*) and have been lodged in the NCW Beadle Herbarium (NE), the Australian National Herbarium (CANB), the National Herbarium of NSW (NSW) and the Queensland Herbarium (BRI).

To look for any additional stands of *Cadellia pentastylis* on nearby hills to the north and south of the Black Jack Mountain population we used binoculars to survey from public roads.

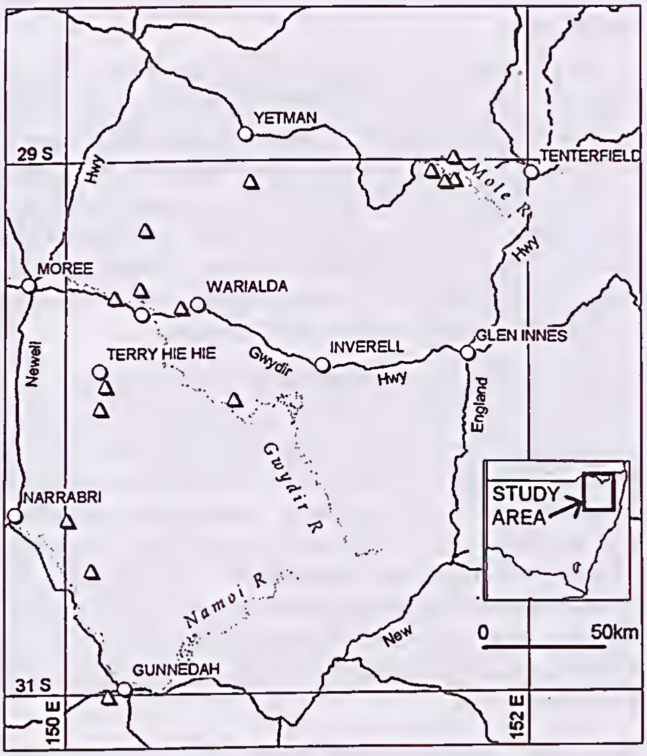

Fig. 1. Location of populations of *Cadellia pentastylis* in NSW. Each population from Table 1 is denoted by a triangle.

Monthly rainfall records for the Gunnedah area for 2004 (Namoi Valley Independent 2005) were compared with long term means from the Bureau of Meteorology (2005) to examine rainfall patterns in the months preceding the flowering and fruiting of *Cadellia pentastylis*.

Results and discussion

Habitat, ecology and statewide distribution

The Black Jack Mountain population of *Cadellia pentastylis* is on the upper slopes of a low hill (31°0'36"S, 150°11'21"E) approximately 7.5 km WSW of Gunnedah, upslope from the former coal washery at Black Jack Colliery, to the north of Black Jack Mountain. There were two separate stands approximately 100 m apart: one on a north-west facing slope; the other on a north and north-east facing slope. The stands typically occur on skeletal sandy loam soils, on generally steep slopes (18–30°) at altitudes of 430–480 m.

The geology of the hillslope is complex, being a mix of igneous rocks, sediments and metamorphosed sediments. The habitat occupied by *Cadellia pentastylis* is predominantly conglomerate, either of the Black Jack Formation of Upper Permian age or Digby Conglomerate of Triassic age (NSW Dept. of Mines 1971a; Dept. of Mineral Resources 1996). Black Jack Mountain, upslope to the south, is capped by igneous rocks interpreted as Tertiary basalt (NSW Dept. of Mines 1971a) or as Glenrowan Intrusives (Late Jurassic sills and dykes) (NSW Dept. of Mineral Resources 1996). Known as the Black Jack Sill, this volcanic cap is listed on the Register of the National Estate as a geological reference site for igneous intrusions (Australian Heritage Commission 1993).

In both stands *Cadellia pentastylis* is the dominant species, with occasional *Geijera parviflora* or *Callitris glaucophylla*, or on the western edge of the western stand, *Eucalyptus albens*, in the canopy. Other small tree species associated with the two *Cadellia pentastylis* stands included *Ehretia membranifolia*, *Notelaea microcarpa* var. *microcarpa*, *Alphitonia excelsa*, *Eremophila mitchellii*, *Capparis mitchellii* and *Alectryon oleifolius* subsp. *elongatus*. Shrubs present included *Croton phebalioides*, *Rhagodia parabolica*, *Beyeria viscosa*, *Acacia decora*, *Maytenus cunninghamii*, *Canthium odoratum*, *Solanum parviflora*, *Abutilon tubulosum*, *Abutilon oxycarpum* and *Olearia* sp. aff. *elliptica*. Vines such as *Parsonia lanceolata*, *Pandorea pandorana* and *Marsdenia viridiflora* were abundant in places and *Parsonsia eucalyptophylla* was also present. The ground cover, which was sparse in places where there was a dense canopy of *Cadellia pentastylis* and other species, comprised grasses such as *Aristida gracilipes*, *Digitaria brownii* and *Cymbopogon refractus*, herbs such as *Malvastrum americanum*, *Einadia nutans* subsp. *linifolia*, and *Einadia hastata*, and the fern *Cheilanthes distans*. Of particular interest was the abundance of the epiphytic orchid, *Cymbidium canaliculatum*, which occurred in high densities on *Cadellia pentastylis*.

The vegetation upslope and to the west of the *Cadellia pentastylis* community was *Eucalyptus albens* shrubby woodland; downslope and to the south of the *Cadellia pentastylis* was semi-evergreen vine thicket (SEVT) dominated by *Ehretia membranifolia*, *Geijera parviflora* and *Notelaea microcarpa* var. *microcarpa*. Many species common to both the SEVT and *Eucalyptus albens* woodland were found in the *Cadellia pentastylis* community.

It is likely that there are more stands of *Cadellia pentastylis* on north-east facing slopes on a low ridge to the north of Black Jack Mountain. This ridge has similar geology to the low ridge we sampled and though we did not visit this area on foot, inspection with binoculars from Black Jack Road showed trees of the same colour and texture as *Cadellia pentastylis*. If this ridge does support *Cadellia pentastylis* it is likely that these stands are considerably larger than the ones reported in this paper. It is also possible that there are smaller stands on the eastern slopes of Black Jack Mountain further south.

While *Cadellia pentastylis* has an extensive, though threatened, distribution in southern Queensland, it is known from only a few locations in NSW (Benson 1993; Geoff Robertson pers. comm.; Table 1; Fig. 1). The population at Black Jack Mountain, Gunnedah is the southern-most known population. To the north the nearest known population is at Turkey Ridge, near Maules Creek approximately 60 km away (Benson 1993). Though the Black Jack Mountain population appears to be one of the smallest in NSW, it is of high conservation significance as it is at the southern distributional limit of the species.

A feature of the Black Jack Mountain population is its proximity to the SEVT community. These two endangered communities share many species (Benson et al. 1996; Keith 2004). Indeed, Keith (2004) included both communities in the Western Vine Thickets vegetation class in his recent statewide overview, though in Queensland *Cadellia pentastylis* communities are treated as a sub-form of SEVT (McDonald 1996; Sattler & Williams 1999).

Table 1. Location, spatial extent, estimated size and geology of *Cadellia pentastylis* populations in NSW. Sources: [1] Benson (1993); [2] DEC (unpubl.); [3] Lachlan Copeland pers. comm.; [4] Hunter (2002); [5] Julian Wall pers. comm.; [6] Forestry Commission of NSW (1989); [7] NSW Dept. of Mines (1971b); [8] this paper. Where all information for a population is from the one source, that source is given with the location, otherwise the source is given for each datum. Populations are arranged in north to south order.

Location	Estimated area (ha)	Estimated population size	Geology
Tenterfield Creek Gorge, W of Tenterfield	100[1]–200+[2]	35 000[1]	Claystone[1]
"Taronga", Mole River	8[2]–10[1]	3900[1]	Claystone[1]
Rock of Gibraltar, W of Tenterfield	21[2]	1000 +[3]	Acid volcanics[3], likely Gibraltar Ignimbrite–ignimbrite rhyolite[4]
Gibraltar Nature Reserve, W of Tenterfield	< 1[5]	< 100[5]	Sediments[5], likely Bodonga Beds–Early Permian conglomerate, sandstone or minor siltstone[4]
Bunal Flora Reserve, Bunal State Forest, NW of Ashford[6]	Unavailable	Unavailable	Jurassic Warialda Sandstones
Crooble	Unavailable – remnant trees[2]	30[2]	Unavailable, possibly Tertiary gravels, sands or clays[7]
Gravesend	75[1]–100[2]	21 000[1]	Sandstone–Claystone[1]
Biniguy	Unavailable[2]	Unavailable [2]	Unavailable, possibly Tertiary gravels, sands or clays[7]
"Tara", Warialda	10[2]–12[1]	2700[1]	Quartz Sandstone[1]
Gamilaraay Nature Reserve and surrounds, Terry Hie Hie[1]	113 (in reserve) + 262 (private land)	122 000	Recrystalised Quartzite - Sandstone
Mehi Flora Reserve, Mehi State Forest, E of Bingara[6]	Unavailable	Unavailable	Ordovician sediments
Campbell State Forest, Terry Hie Hie	Few plants[2]	Few plants[2]	Unavailable, possibly Jurassic Warialda Sandstone or Rocky Creek Conglomerate[7]
Deriah State Forest and nearby areas (e.g. Eulah Creek), Narrabri	186[1]–240[2]	54 000[1]	Alluvium / Lithic Sandstone / Claystone[1]
Turkey Ridge, Maules Creek	350[2]–400[1]	74 000[1]	Wean Formation Conglomerate[1]
Black Jack Mt, Gunnedah[8]	2	1000	Conglomerate (Digby or Black Jack Formation)

Benson et al. (1996) observed that in NSW SEVT and *Cadellia pentastylis* communities do not mix. In recent extensive sampling of dry rainforest vegetation (including SEVT and *Cadellia pentastylis* communities) on the western slopes of NSW (Curran in prep.), *Cadellia pentastylis* was not encountered growing with SEVT, though some stands, e.g. parts of the Deriah State Forest and Warialda populations, are very similar to SEVT in species composition. On Black Jack Mountain, there were extensive stands of SEVT, including patches immediately downslope and across-slope (to the south) from the *Cadellia pentastylis*. The igneous (basalt or dolerite) influence on parts of the hill, coupled with the likely deeper soils further downslope, could explain the presence of SEVT in such close proximity to *Cadellia pentastylis*. Benson (1993) noted a strong correlation between *Cadellia pentastylis* and either lithic sandstone or conglomerate substrates (see Table 1), and observed that southern stands tend to have northerly aspects. These patterns are consistent with the Black Jack Mountain population, which occurs on northerly aspects on conglomerate. This represents a likely stressful habitat, being both low in nutrients and low in moisture availability (likely on sandy loam or sandy clay and often skeletal soils with northerly aspect exposed to desiccating winds). In contrast, SEVT is mostly associated with higher nutrient, basalt-derived soils (Benson et al. 1996), though it does occur on conglomerates of the Black Jack Formation south of Curlewis (Curran in prep.). The vegetation of Black Jack Mountain may provide a natural laboratory to further explore the causal factors underpinning the distinction between SEVT and *Cadellia pentastylis* communities.

The Black Jack Mountain population of *Cadellia pentastylis* is largely unaffected by two of the major threats to the species - land-clearing and livestock over-grazing (Benson 1993). Though located on private land near a former coal mine, there is no immediate threat of land-clearing as the mine has closed down and the mine site is being restored. This presents an opportunity to plant additional *Cadellia pentastylis* nearby, though there is no evidence to suggest that the population has been reduced in extent by past clearing. However, there are some stumps of unidentified trees downslope of the population. The area is not currently grazed by livestock. A potential threat to the population is the lack of recruitment; further research is needed to assess the implications of this. While *Cadellia pentastylis* may be vulnerable to fire (Benson 1993), there is nothing to suggest there is a high fire threat at Black Jack Mountain, and the limited access to the site (via private road) helps prevent arson.

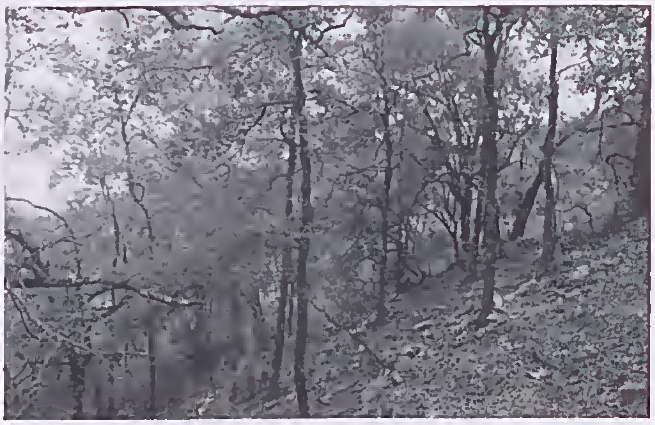

Fig. 2. Dense stand of *Cadellia pentastylis* at Black Jack Mountain, Gunnedah showing thick leaf litter and sparse ground cover. Plot 4 was located in this stand.

Population size

The two stands of *Cadellia pentastylis* occupy approximately 2 ha — western stand 0.9 ha, eastern stand 1.0 ha. Sampling in the eastern stand showed a range of densities (Table 2); from 175 plants per ha in the sparsely populated Plot 3, to 1125 per ha in a plot with particularly dense *Cadellia pentastylis* (Plot 4; Fig. 2). The average density was 531 ±206 per hectare, giving a total estimate of 1009 ±392 plants for the two stands on Black Jack Mountain.

Flowering and fruiting and timing in relation to rainfall

Bob Howarth collected the flowering specimen of *Cadellia pentastylis* in 1994 in the middle of a severe drought in the Gunnedah area. Drawing on anecdotal information from landholders near other *Cadellia pentastylis* stands in NSW, Benson (1993) suggested that the species appeared to flower sporadically, with the last (i.e. pre 1988) previous profuse flowering reported from October 1986, which was

Table 2. Number of individuals of *Cadellia pentastylis* of different size classes in each of four 20 m x 20 m plots and mean stems per ha in the eastern stand on Black Jack Mountain, Gunnedah

	Stems / 0.04 ha				
Size class	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Mean stems /ha (± s.e.)**
Large tree (> 10 cm DBH)	14	9	7	15	281 (± 48)
Small tree (< 10 cm DBH)	4	6	0	30	250 (± 169)
Seedling (< 50 cm height)	0	0	0	0	0
Total plants	**18**	**15**	7	**45**	**531 (± 206)**

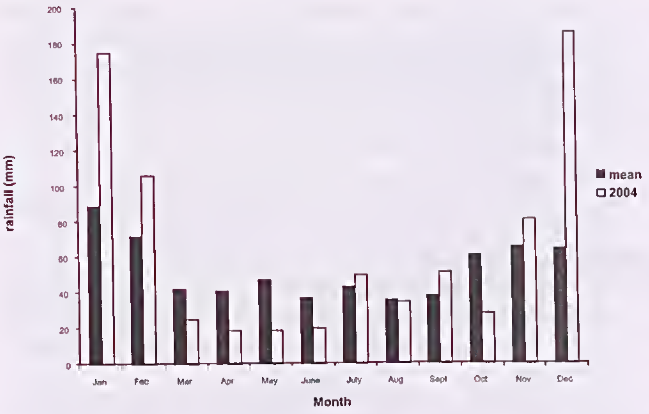

Fig. 3a. Monthly rainfall for Gunnedah for 2004 (Namoi Valley Independent 2005) and long term monthly mean rainfall for Gunnedah Soil Conservation Station (Bureau of Meteorology 2005). The most extensive recent flowering of *Cadellia pentastylis* was in November 2004.

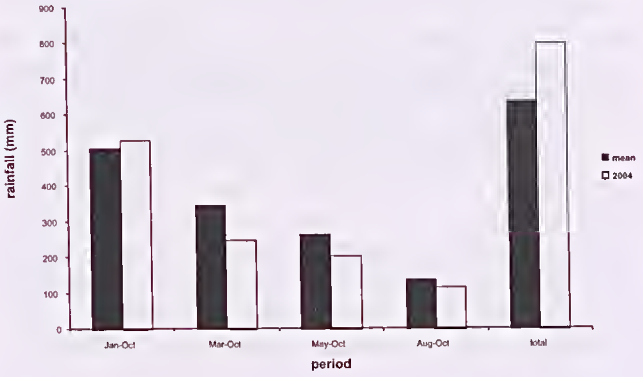

Fig. 3b. Comparison of rainfall at Gunnedah for 2004 against long term means for three month (Aug-Oct), six month (May-Oct), eight months (Mar-Oct) and 10 months (Jan-Oct) prior to 31st October 2004, and the flowering of *Cadellia pentastylis* in November 2004. Data sources as per Fig. 3a.

a dry year on the North Western Slopes. More recently, the species was noted fruiting extensively in December 2002 at Rock of Gibraltar, west of Tenterfield (Lachlan Copeland, pers. comm.), at the height of a very severe drought in NSW (Bureau of Meteorology 2003).

In 2004 Gunnedah recorded above average rainfall of 795 mm (Namoi Valley Independent 2005) against a long term average of 636 mm (Bureau of Meteorology 2005). This was mainly due to large falls in January (175 mm), February (106 mm) and December (186 mm) (Fig. 3a). In the Narrabri and Gunnedah areas the most recent extensive flowering of *Cadellia pentastylis* was in November 2004. Despite the above average rainfall at Gunnedah in 2004, the months preceding the likely onset of flowering were characterized by drier conditions - rainfall was below average for the three, six and eight month periods to 31st October 2004 (Fig. 3b). This suggests that this recent flowering of *Cadellia pentastylis* might also have been triggered by dry conditions.

There was prolific fruiting in the *Cadellia pentastylis* population prior to and during sampling; and large amounts of seed were lying on the ground. Some was collected for germination trials.

No seedlings were recorded in any of the plots, though there were four probable seedlings on the south-eastern edge of the population. However, because these were close to an adult stem (i.e. within 5 m) it is possible that they were simply young coppicing stems from the adult plant. Benson (1993) noted that seedlings were rarely observed and were not present at some sites. However, as in other populations in NSW (Benson 1993), there were frequent examples of coppicing in the Black Jack Mountain population.

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We wish to thank Bob Howarth for drawing our attention to the population at Gunnedah and for showing us the location. Penny Gardiner and Terry Curran assisted with field work or logistics and are thanked for their general support. Chris Burgess, Site Manager, Black Jack Colliery, gave us permission to access the stands described in this paper. Ian Telford, Geoff Robertson, James Faris, Sue Cox, Lachlan Copeland, Paul Sheringham, Peter Hind, Travis Peake, Stephen Bell, Bill McDonald, Julian Wall, Joanne Lello, Don Butler, Peter Clarke, John Williams and Jeremy Bruhl are gratefully thanked for information concerning *Cadellia pentastylis* and/or comments on the draft manuscript. Comments from Doug Benson and anonymous reviewers improved the text. Dave Mitchell kindly prepared the map of *Cadellia pentastylis* populations.

Finally, we wish to dedicate this paper to the late John B. Williams, Fellow of the University of New England, who recently passed away. John taught Botany to SRC and had many discussions with TJC on ooline and dry rainforest vegetation. His sharp insights, gentle nature and companionship will be sorely missed.

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Floristics and distribution of Wattle Dry Sclerophyll Forests and Scrubs in north-eastern New South Wales

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Abstract: *Acacia blakei* forests and scrubs of north-eastern NSW are described and compared to similar vegetation found in the south-east of the state, primarily dominated by *Acacia silvestris*. Like those in the south, Northern Wattle Dry Sclerophyll Forests form often discrete stands with abrupt margins on steep slopes in rugged terrain on shallow often rocky soils. The structure is usually of a cohort with stems of an even height and size up to 20 m tall, and a sparse understorey with few grasses, herbs or shrubs. These systems are potentially maintained by infrequent extreme fire events. Notes are made on their management and conservation.

***Cunninghamia* (2005) 9(2): 317–323**

Introduction

Clayton-Greene & Wimbush (1988) were the first to fully describe an unusual vegetation association of dense *Acacia*-dominated scrubs and forests on the eastern fall of the Great Dividing Range in southern NSW. This class of vegetation, primarily dominated by *Acacia silvestris* (Bodalla Silver Wattle), occurred between the Byadbo region of the Snowy Mountains to south of Deddick in Victoria. The assemblage was characterised by being composed of dense stands of *Acacia* often of a uniform height, with very little understorey (sparse in grasses with only scattered smaller shrubs), and occurring on steep north and west-facing slopes, on metasediments or coarse grained granite. The edges of these *Acacia* scrubs were sharp and clearly-defined.

Similar vegetation, called 'Black Jungle' or 'Black Scrub", was classified under Forest Type 214 (Anon 1989), and as *Acacia* Scrub (Map Unit 4) by Keith & Bedward (1999) in their mapping of south-eastern NSW forests. Though *Acacia silvestris* was the most common dominant, other wattles such as *Acacia binervia, Acacia doratoxylon, Acacia falciformis* and *Acacia kettlewelliae* sometimes formed similarly structured assemblages (Clayton-Greene & Wimbush 1988; Keith & Bedward 1999). Keith (2004) considered that these assemblages showed little close affinity with other vegetation classes but did share taxa with rock outcrop communities.

Keith (2004) considered these *Acacia*-dominated systems, which he termed Southern Wattle Dry Sclerophyll Forests, as a curious anomaly, as the only (non-regrowth) class of vegetation in eastern flowing catchments of the Great Dividing Range to be dominated by *Acacia* rather than *Eucalyptus*. Similar vegetation however has been reported elsewhere in eastern NSW for over a decade. Stands dominated by *Acacia bulgaensis* occur in the Wollemi, Yengo, Parr and Pokolbin areas west of Newcastle (Bell et al. 1993; Binns 1996). Vegetation dominated by *Acacia blakei* subsp. *diphylla* occurs in areas north from Gloucester (Binns 1994; Binns 1995; Anon 1995; Hunter 1998; Hunter et al. 1998; Benwell 2000; Hunter 2004). Extensive field investigations have highlighted that the latter northern vegetation, in particular, mirrors the physical and structural characteristics of the southern scrubs and forests. Here I describe, compare and contrast these Northern Wattle Dry Sclerophyll Forests and Scrubs with those from southern NSW.

Occurrences in Northern New South Wales

Many assemblages similar to the 'Black Scrubs' of south-eastern NSW have been reported. Binns (1994) described an *Acacia blakei* subsp. *diphylla–Plectranthus graveolens* low forest or woodland from the Chaelundi area north of Dorrigo. An *Acacia blakei* subsp. *diphylla* forest association was noted near the Henry River Falls on metasediments in Guy Fawkes River National Park (Anon 1995). Benwell (2000) described an *Acacia blakei* subsp. *diphylla* scrub associated with low quartz sedimentary rock types and acid volcanics in Nymboida National Park. Benwell (2000) also discusses finding similar stands within Guy Fawkes River National Park. Extensive stands of *Acacia blakei* scrub also occur within Oxley Wild Rivers National Park (*pers. obs.*) where they are quite extensive compared to other northern occurrences. These stands are often associated with dry rainforest, and due to their similar colour on aerial photographs may be included in dry rainforest mapping units (CRA 1999). Table 1 compares features shown by the southern and northern stands.

The Demon Fault, the western boundary of Demon Nature Reserve, runs along the western base of the Malara Plateau east of Tenterfield. Along this geological feature is a distinct linear patch of vegetation dominated by *Acacia blakei* subsp. *diphylla* which forms a dense cohort of scrub on the steep western facing slopes (Hunter et al. 1998). The *Acacia* scrub

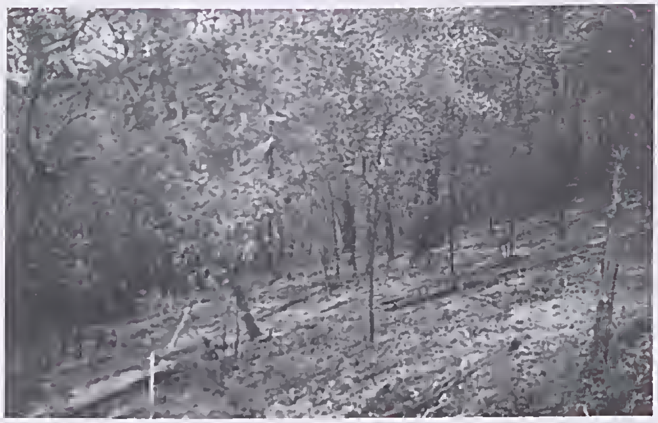

Fig. 1. *Acacia blakei* scrubs on the Demon Fault within the Demon Nature Reserve.

forms a distinct linear patch whose boundary is clear and sharp within a larger *Eucalyptus* forest. The understorey was sparse with scattered grasses and a few shrubs (Fig. 1). The height of most of the stand was only 4 to 8 m but some sections consisted of much older cohorts.

Stands of *Acacia blakei* forests and scrubs were found on steep north and western facing slopes in dissected metasediment gorge country within the Washpool National Park western additions (Hunter 1998). These stands occurred on shallow soils but had sharp and distinct boundaries with the surrounded *Eucalyptus*-dominated forests. The understorey was very sparse, with only a few grasses and some scattered smaller shrubs. The dominant *Acacia blakei,* up to a height of 20 m, formed a cohort of similar-aged individuals with little recruitment evident (Fig. 2). In floristic analyses this community was closely allied to rock outcrop assemblages which they sometimes occur around (Hunter 1998).

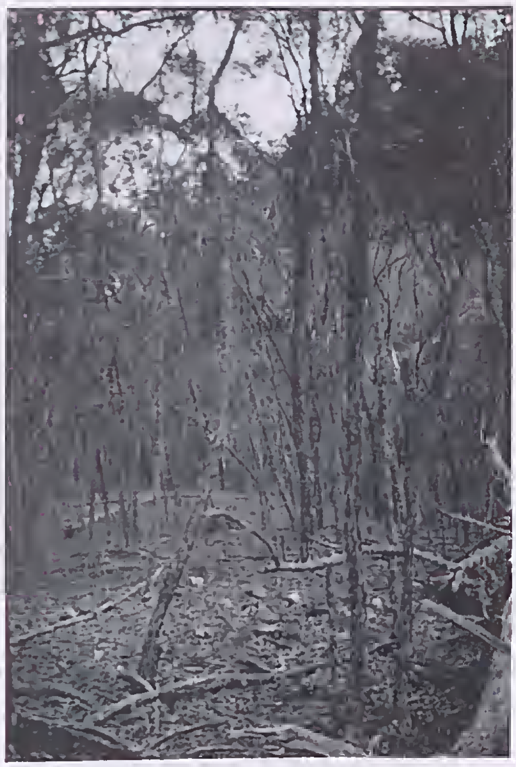

Fig. 2. Stand of *Acacia blakei* forest within Washpool National Park.

Hunter (2004) described stands of *Acacia blakei* subsp. *diphylla* forests and scrubs within Mann River Nature Reserve. The stands were often associated with shallow soils on northerly facing slopes of course grained granite. These stands often also occurred around rock outcrops and were floristically associated with outcrops in floristic analyses

Table 1. Comparison of Southern Wattle Dry Sclerophyll Forest (sensu Keith 2004) and Northern Wattle Dry Sclerophyll Forests. Information for southern localities derived from Clayton-Greene & Wimbush (1988), Keith & Bedward (1999) and Keith (2004).

Characteristic	Southern Wattle DSF	Northern Wattle DSF
Dominant taxon	*Acacia silvestris* sometimes *A. kettlewelliae*, rarely *A. doratoxylon* or *A. falciformis*	*Acacia blakei* subsp. *diphylla* sometimes *A. blakei* subsp. *blakei*
Boundaries	Discrete & very abrupt within a sea of Eucalypt forest	Discrete & very abrupt within a sea of Eucalypt forest
Slopes	Steep north & west facing	Steep to gentle primarily north & west facing, sometimes east facing.
Landscape	Usually in remote, dissected terrain	Remote dissected terrain
Soil	Shallow & rocky	Shallow & rocky
Rock type	Metasediments and course grained granite	Metasediments and course grained granite, rarely acid volcanics
Canopy	Generally uniform, closed canopies, stems of similar height & size away from ecotone	Generally uniform, closed canopies, stems of similar height & size away from ecotone
Diameter at breast height	0.8–20 cm. Average 4.4 cm ± 3.3 cm.	16.1–37.5 cm. Average 22 cm ± 6 cm. (Mann River)
Height	5 to 20 m tall	5 to 20 m tall
Understorey	Sparse, little ground cover, few grasses, some scattered shrubs	Sparse, little ground cover, few grasses, some scattered shrubs
Floristic relationships	With rock outcrop floras	With rock outcrop floras
Occurrence	3585 ha (south eastern NSW Keith & Bedward 1999)	Possibly 700 ha

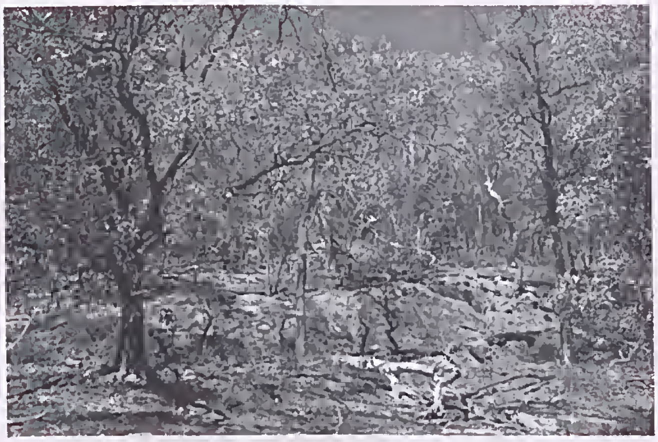

Fig. 3. *Acacia blakei* forests within the Mann River Nature Reserve.

(Hunter 2004). As with the previously described stands the understorey was sparse and open and the boundaries of the patches were clear and distinct within a general *Eucalyptus* forest and woodland matrix, although scattered *Acacia* individuals were commonly found in other forests and woodlands. The *Acacia* stands were mainly of even size within each patch though different patches were often different heights. In most patches the stems were 10–18 m tall, with stem diameters (dbh) averaging 22 cm (Fig. 3).

Based on full floristic field survey sites *Acacia blakei* communities typically contain the shrub *Ficus rubiginosa;* the forbs *Cheilanthes sieberi* subsp. *sieberi*, *Commelina cyanea, Desmodium varians, Dianella caerulea, Galium aspera, Lomandra longifolia, Lomandra multiflora, Opercularia hispida, Pomax umbellata, Pratia purpurascens, Scleria mackaviensis, Sigesbeckia australiensis* and *Hybanthus stellarioides*; the grasses *Cymbopogon refractus, Entolasia stricta, Oplismenus aemulus* and *Themeda australis*.

Acacia blakei appears to be the only species that forms these clear and distinct assemblages with these ecological characteristics in the eastern flowing catchments of northern NSW. The abrupt and clear boundaries of these systems are distinctive in many situations, but in some situations the boundaries (as with many vegetation communities) can be extended and somewhat blurred (as is the situation in the southern occurrences as well - Clayton-Greene & Wimbush 1988). Other wattle taxa, such as *Acacia falciformis, Acacia dealbata, Acacia elata, Acacia irrorata*, often form dense stands but only as an understorey component of *Eucalyptus* forests or as short-term (i.e. > 20 yrs) regrowth following disturbance in sites that will eventually support eucalypt forests.

Similar vegetation on western flowing catchments of the north-east

On the western flowing catchments on the Northern Tablelands and North Western Slopes structurally similar wattle forests and scrubs also occur, and are dominated by taxa with broad affinities to *Acacia blakei* (Juliflorae) and which share the same site characteristics (Fig. 4). Between Deepwater and Tenterfield *Acacia pycnostachya* forms scrubs and forests in Bolivia Hill and Bluff River Nature Reserves (Hunter & Clarke 1998; Hunter 2002). In the northern parts of the Northern Tablelands *Acacia pubifolia* forms similar stands at Torrington, and in Queensland within Girraween and Sundown National Parks (Hunter & Clarke 1998). *Acacia cheelii* forms dense cohort stands in the south-west of the Northern Tablelands at Mt Kaputar and Warrabah National Parks and at Ironbark and Melville Range Nature Reserves (Hunter & Clarke 1998; Hunter & Alexander 2000; Hunter & Hunter 2003). In north-west New England, *Acacia williamsiana* forms structurally similar stands in similar situations at Torrington State Recreation Area, Kwiambal and Kings Plains National Parks and Severn River Nature Reserve (Hunter 1997; Hunter & Clarke 1998; Hunter et al 1999; Hunter 2000ab).

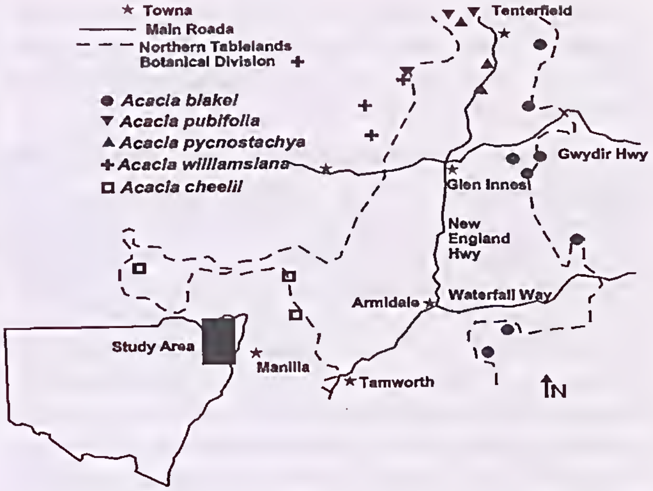

Fig. 4. Known locations of Wattle Dry Sclerophyll Forests and Scrubs of north-eastern New South Wales. *Acacia blakei* is the only taxon dominating these communities in eastern flowing catchments.

Management and conservation

Clayton-Greene & Wimbush (1988) showed that the 'Black Scrubs' of south-eastern NSW were long-lived with some trees of *Acacia silvestris* and *Eriostemon trachyphyllus* having ring-counts indicating ages of up to 100 years or more, though most appeared to be between 25 and 35 years old. These scrubs did not appear to carry low intensity fires probably due to the sparse understorey and the comparative lack of flammability of *Acacia* leaves (Clayton-Green & Wimbush 1988). However due to lack of resprouting ability the dominant wattles were likely to be killed by fire (Keith 2004). Such evidence, along with investigations of previous fire patterns, lead Clayton-Green & Wimbush (1988) to surmise that these scrubs were maintained by infrequent intense fire events, and that they may not persist in the absence of such events. Each cohort is likely to be related to a specific intense wildfire event (Keith 2004). A very similar dynamic was proposed for rock outcrop floras of northern NSW with which these scrubs and forests are closely allied (Hunter et al. 1998; Hunter 2003).

Within eastern NSW potentially less than 5 000 ha of this vegetation may exist north of the Hunter region. Around 700 ha have been mapped in northern NSW though it is likely that not all stands have been recorded. In the south-east where more extensive investigations have occurred, 3585 ha are known. These distinctive communities are probably part of a long-term dynamic reliant on unique site characteristics and extreme fire events. In 1988 Clayton-Greene and Wimbush suggested that the only conceivable threat to the continued existence of the southern scrubs would be attempts to exclude intense fire by too-frequent low-intensity burns in the surrounding woodland. Under such regimes the likelihood of these wattle scrubs and forests persisting in landscapes where extreme fire events are actively discouraged by management activities may be reduced. Although most occurrences in northern NSW are within reserves managed by the National Parks and Wildlife Service; most are small and isolated stands and they may be under threat while we do not understand the mechanisms enabling persistence. These communities should be perceived as both a significant and unusual vegetation association of limited extent.

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Appendix 1. List of vascular plant species associated with *Acacia blakei* Dry Sclerophyll Forests and Scrubs of eastern flowing catchments of north-eastern NSW. Taxa were recorded from field plots. Nomenclature follows that of Harden (1992-2002) Flora of New South Wales, except where recent changes have been made.

DM = Demon Nature Reserve (5 x 0.1 ha sites).
MR = Mann River Nature Reserve (4 x 0.1 ha sites).
NY = Nymboida National Park (Benwell 2000).
WWP = Washpool National Park Western Additions (3 sites).

PTERIDOPHYTES

Adiantaceae

Adiantum hispidulum	NY, WWP
Cheilanthes distans	DM, MR
Cheilanthes sieberi subsp. *sieberi*	DM, MR, NY, WWP
Pellaea falcata	WWP
Pellaea nana	DM

Aspleniaceae

Asplenium flabellifolium	WWP

Polypodiaceae

Pyrrosia rupestris	NY

MONOCOTYLEDONS

Anthericaceae

Arthropodium milleflorum	DM
Tricoryne anceps var. *pterocaulon*	DM, WWP

Commelinaceae

Commelina cyanea	DM, MR, WWP

Cyperaceae

Cyperus imbecillis	DM
Cyperus fulvus	MR
Cyperus gracilis	MR, NY
Cyperus lhotskyanus	DM
Fimbristylis dichotoma	DM, MR
Gahnia aspera	DM, MR, NY, WWP
Lepidosperma laterale	DM, WWP
Schoenus melanostachys	DM, MR
Scleria mackaviensis	DM, MR, WWP

Haemodoraceae

Haemodorum planifolium	DM

Iridaceae

Patersonia glabrata	WWP
Patersonia sericea	DM

Lomandraceae

Lomandra confertiflora	DM
Lomandra filiformis	DM
Lomandra longifolia	DM, MR, WWP
Lomandra multiflora subsp. *multiflora*	DM, MR, WWP
Eustrephus latifolius	DM, WWP
Geitonoplesium cymosum	NY

Orchidaceae

Acianthus apprimus	DM
Bulbophyllum minutissimum	MR
Dendrobium kingianum	MR

Phormiaceae

Dianella caerulea var. *caerulea*	DM, MR, NY, WWP

Poaceae

Aristida acuta	MR
Aristida calycina var. *calycina*	MR
Aristida jerichoensis subsp. *subspinulifera*	DM
Aristida ramosa var. *ramosa*	MR
Austrodanthonia racemosa var. *racemosa*	MR
Austrostipa rudis subsp. *nervosa*	WWP
Austrostipa scabra subsp. *scabra*	MR
Cenchrus caliculatus	MR, WWP
Cymbopogon refractus	DM, MR, NY, WWP
Deyeuxia mckiei	DM
Dichelachne micrantha	MR, WWP
Dichelachne rara	DM
Digitaria breviglumis	DM, MR
Digitaria diffusa	MR
Digitaria ramularis	MR, WWP
Echinopogon caespitosus var. *caespitosus*	MR
Echinopogon ovatus	DM
Entolasia marginata	MR, WWP
Entolasia stricta	DM, MR, NY, WWP
Eragrostis elongata	DM, MR
Eragrostis leptostachya	MR
Eragrostis molybdea	MR
Joycea pallida	MR
Microlaena stipoides	DM
Notodanthonia longifolia	DM, WWP
Oplismenus aemulus	DM, MR, WWP
Oplismenus imbecillis	NY
Oplismenus undulatifolius var. *mollis*	DM, MR
Panicum effusum	MR
Panicum simile	DM
Paspalidium constrictum	DM
Poa labillardieri	DM, WWP
Poa sieberiana var. *sieberiana*	MR
Sorghum leiocladum	WWP
Themeda australis	DM, MR, WWP
Tripogon loliiformis	DM, MR

Restionaceae

Baloskion stenocoleum	DM

Smilacaceae

Smilax australis	NY

DICOTYLEDONS

Acanthaceae

Brunoniella australis	WWP

Apiaceae	
Trachymene incisa subsp. *incisa*	DM, MR
Apocynaceae	
Alyxia ruscifolia	NY, MR
Parsonsia straminea	DM
Araliaceae	
Astrotricha longifolia	WWP
Asclepiadaceae	
Hoya australis subsp. *australis*	MR
Sarcostemma brunonianum	MR
Asteraceae	
**Bidens pilosa*	DM, MR, WWP
Brachyscome microcarpa	DM
Calotis dentex	MR, WWP
Cassinia uncata	WWP
Chrysocephalum apiculatum	DM
**Cirsium vulgare*	WWP
**Conyza albida*	DM
Euchiton sphaericus	MR, WWP
Glossogyne tannensis	DM
**Gnaphalium americanum*	DM
**Hypochaeris radicata*	DM, MR, WWP
Lagenifera gracilis	DM
Senecio diaschides	MR, WWP
Senecio hispidulus var. *hispidulus*	MR
Senecio lautus subsp. *dissectifolius*	MR
Senecio lautus subsp. *lanceolatus*	WWP
Senecio vagus subsp. *eglandulosus*	WWP
Sigesbeckia australiensis	DM, MR, WWP
Veronica cinerea var. *cinerea*	DM, WWP
Vittadinia cervicularis subsp. *subcervicularis*	DM, MR
**Zinnia peruviana*	MR
Bignoniaceae	
Pandorea pandorana	DM, MR
Campanulaceae	
Wahlenbergia communis	DM, WWP
Wahlenbergia luteola	DM
Casuarinaceae	
Allocasuarina littoralis	MR, WWP
Allocasuarina torulosa	DM
Celastraceae	
Maytenus silvestris	DM, WWP
Chenopodiaceae	
Chenopodium carinatum	MR
Einadia trigonos subsp. *leiocarpa*	WWP
Clusiaceae	
Hypericum gramineum	DM
Convolvulaceae	
Dichondra repens	DM, WWP
Dichondra sp. A	MR
**Ipomoea cairica*	MR
Polymeria calycina	DM
Crassulaceae	
Crassula sieberiana	DM, MR
Dilleniaceae	
Hibbertia obtusifolia	DM, MR
Epacridaceae	
Leucopogon lanceolatus var. *lanceolatus*	WWP
Melichrus urceolatus	DM
Escalloniaceae	
Rapanea variabilis	NY
Euphorbiaceae	
Acalypha nemorum	DM, NY
Beyeria viscosa	WWP
Breynia cernua	DM, NY
Phyllanthus gunnii	DM, NY, WWP
Poranthera microphylla	DM
Ricinocarpos speciosus	MR
Fabaceae	
Acacia blakei subsp. *diphylla*	DM, MR, NY, WWP
Bossiaea scortechinii	DM
Desmodium brachypodum	DM, MR
Desmodium rhytidophyllum	DM
Desmodium varians	DM, MR, WWP
Glycine clandestina	DM
Glycine microphylla	DM
Jacksonia scoparia	DM, MR
Mirbelia pungens	DM
Podolobium ilicifolium	DM
Goodeniaceae	
Dampiera stricta	MR
Goodenia hederacea	DM
Goodenia rotundifolia	DM
Haloragaceae	
Haloragis heterophylla	DM
Gonocarpus oreophilus	NY
Gonocarpus teucrioides	WWP
Lamiaceae	
Ajuga australis	DM
Mentha diemenica	DM
Plectranthus graveolens	DM, MR
Plectranthus parviflorus	DM, MR, WWP
Plectranthus suaveolens	MR
Prostanthera nivea	DM
Lobeliaceae	
Pratia purpurascens	DM, MR, WWP
Loranthaceae	
Muellerina celastroides	MR
Muellerina eucalyptoides	MR
Malvaceae	
Hibiscus trionum	MR

Moraceae	
Ficus rubiginosa forma *glabrescens*	DM, MR, NY
Myrtaceae	
Babingtonia collina	MR
Corymbia gummifera	DM
Corymbia variegata	NY
Eucalyptus biturbinata	MR
Eucalyptus campanulata	WWP
Eucalyptus crebra	MR
Eucalyptus dorrigoensis	WWP
Eucalyptus fibrosa	DM
Eucalyptus prava	MR
Eucalyptus propinqua	DM
Eucalyptus radiata subsp. *sejuncta*	WWP
Eucalyptus tereticornis	MR
Leptospermum arachnoides	MR
Leptospermum petersonii subsp. *petersonii*	MR
Leptospermum polygalifolium subsp. *transmontanum*	DM, WWP
Lophostemon confertus	DM, MR
Nyctaginaceae	
Boerhavia dominii	DM
Oleaceae	
Jasminum volubile	MR
Notelaea longifolia	DM, NY
Oxalidaceae	
Oxalis chnoodes	WWP
Oxalis perennans	DM
Passifloraceae	
Passiflora aurantia	WWP
Pittosporaceae	
Billardiera scandens var. *scandens*	DM
Bursaria spinosa	WWP
Polygalaceae	
Rumex brownii	WWP
Portulacaceae	
Calandrinia pickeringii	DM
Primulaceae	
**Anagallis arvensis*	MR

Proteaceae	
Hakea sericea	DM
Lomatia silaifolia	WWP
Plantaginaceae	
Plantago varia	WWP
Rhamnaceae	
Alphitonia excelsa	MR, NY
Persoonia sericea	
Pomaderris elliptica	DM
Rubiaceae	
Opercularia aspera	MR, WWP
Opercularia diphylla	MR
Opercularia hispida	DM, MR, WWP
Pomax umbellata	DM, MR, WWP
Rutaceae	
Asterolasia correifolia	MR
Correa reflexa var. *reflexa*	DM, WWP
Zieria smithii subsp. *smithii*	WWP
Solanaceae	
Solanum campanulatum	DM, MR, WWP
Santalaceae	
Exocarpus cupressiformis	WWP
Scrophulariaceae	
Veronica calycina	WWP
Veronica plebeia	WWP
Sterculiaceae	
Brachychiton populneus subsp. *populneus*	DM, MR
Lasiopetalum ferrugineum var. *cordatum*	MR
Ulmaceae	
Trema tomentosa	DM, NY
Verbenaceae	
Clerodendrum tomentosum	NY
Violaceae	
Hybanthus monopetalus	DM
Hybanthus stellarioides	DM, NY, WWP
Viola betonicifolia	DM
Viola hederacea	DM
Viscaceae	
Notothixos subaureus	MR

Is there a diel pattern to nectar secretion in the Red Bloodwood *Corymbia gummifera*?

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Abstract: Nectar secretion was measured at 6-h intervals over a 24-h period in flowers of the Red Bloodwood, *Corymbia gummifera* (family Myrtaceae). Secretion varied among time periods and among trees. There was no clear diurnal or nocturnal pattern. Flowers produced 0.5–3 µl of dilute nectar (9% concentration) per hour throughout the diel cycle. Standing crops of nectar averaged 1–12.6 µl per flower and also varied temporally and spatially. Flowers were visited by a wide array of nectarivores: insects, birds, gliding possums and bats. Although it is likely that these visitors vary considerably in their effectiveness as pollinators, it would appear that *Corymbia gummifera* has a generalised pollination system.

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Introduction

Despite the enormous ecological value of eucalypts (species of *Eucalyptus* and *Corymbia*), to Australian biodiversity, relatively few studies have been conducted to assess the interactions between eucalypts and their nectar-feeding visitors (see House 1997). Hopper and Moran (1981) concluded 24 years ago that the study of the pollinators of eucalypts was in its infancy. However, this situation has improved little in the intervening period.

Several studies have been completed that document the feeding behaviour of eucalypt nectarivores. Field studies on petaurid gliding possums have revealed that eucalypt nectar and pollen are common elements of their diet and are likely to feature in the diet wherever these species occur (Kavanagh 1987; Howard 1989; Goldingay 1990; Quin et al. 1996; Sharpe & Goldingay 1998; Jackson 2001; Dobson et al. 2004). Only Goldingay (1990) has considered the implications for pollination of regular flower visitation by these marsupials. There have been few advances in the last 10 years of documenting visitation by birds, bats and insects to eucalypts despite the dominance of these trees in the Australian landscape (see McGoldrick & MacNally 1998; Horskins & Turner 1999; Palmer & Woinarski 1999; Palmer et al. 2000; Hingston & McQuillan 2000). Some work was conducted on honeyeater birds and their food plants prior to this (e.g. Ford et al. 1979; Pyke 1985) and on foraging by flying-foxes (Eby 1991). Therefore, our understanding of the pollinators of eucalypts has progressed little and we are a long way from describing the relative contribution to pollination of different pollinators.

The notion that plants exhibit specific traits (referred to as syndromes) that have co-evolved with their primary pollinators has been around for some time (e.g. Baker 1961; Rourke & Wiens 1977; Faegri & van der Pijl 1979). Despite this, there have been few attempts to test this among Australian plants. Hingston and McQuillan (2000) documented a large set of plant visitor profiles, including 11 species of eucalypt, to test visitor predictions based on floral morphology. They concluded there was a lack of specialisation. Saffer (2004) categorised six plant species as predominately bird or mammal-pollinated and determined whether patterns of anthesis and nectar production were consistent with predictions for these pollinators. She concluded that the lack of concordance was suggestive of a generalised pollination system.

Describing patterns of anthesis and nectar production is basic to understanding the ecology of different plant species. It is not only important in providing insights into whether plants are predominantly visited by diurnal or nocturnal pollinators, but will also provide insights into food resource availability and how this may influence foraging by specific floral visitors. Few studies have described patterns of nectar production in eucalypts but this is needed to properly understand interactions between these dominant trees in Australia and their visitors. The aim of this study was to describe the pattern of nectar production in the Red Bloodwood, *Corymbia gummifera* (formerly *Eucalyptus gummifera*), a dominant tree species in coastal New South Wales that is commonly visited by many species of vertebrate.

Methods

Study area

This study was conducted in Murramarang National Park (35° 35′ S, 150 ° 19′ E), approximately 20 km north-west of Batemans Bay on the New South Wales south coast. The study area was dominated by *Corymbia maculata*, *Corymbia gummifera* and *Eucalyptus pilularis*, but also contained *Eucalyptus scias* and *Eucalyptus piperita*. Tree canopies ranged from 20 to 45 m above the ground. At this site, *Corymbia gummifera* typically flowers between February and May but not every year (Goldingay 1990).

Nectar sampling

Sampling of nectar from eucalypt flowers at the site was difficult because tree canopies were at least 10 m above the ground. In the first year of sampling (5–6/4/1987), only a single tree was sampled. A caving ladder was attached to a branch at about 10 m above the ground to gain access to flowers. In the second year of sampling (19–21/4/1988), a mini-cherrypicker was used which enabled access to four trees. These trees were located along 200 m of an unsealed forest road and were selected based on ease of access with the cherrypicker, which had to be repositioned to sample each tree.

On each of the five trees, 6–10 flowers on a single branch were initially emptied of nectar between 1300–1700 h. All flowers were in a middle development stage where they had some upright stamens while others were reflexed (see Bond & Brown 1979; Horskins & Turner 1999). This was assumed to be the time of highest secretion in *Corymbia gummifera* as it was for *Eucalyptus costata*. Once emptied of nectar, flowers were covered with a fibreglass mesh bag to prevent access by nectar-feeding animals. In year 2, each tree was sampled one after the other. The amount of nectar secreted by each flower was measured using a microcapillary tube at approximately 6-h intervals beginning at 1800 h. The exact times of sampling were recorded so the secretion rates

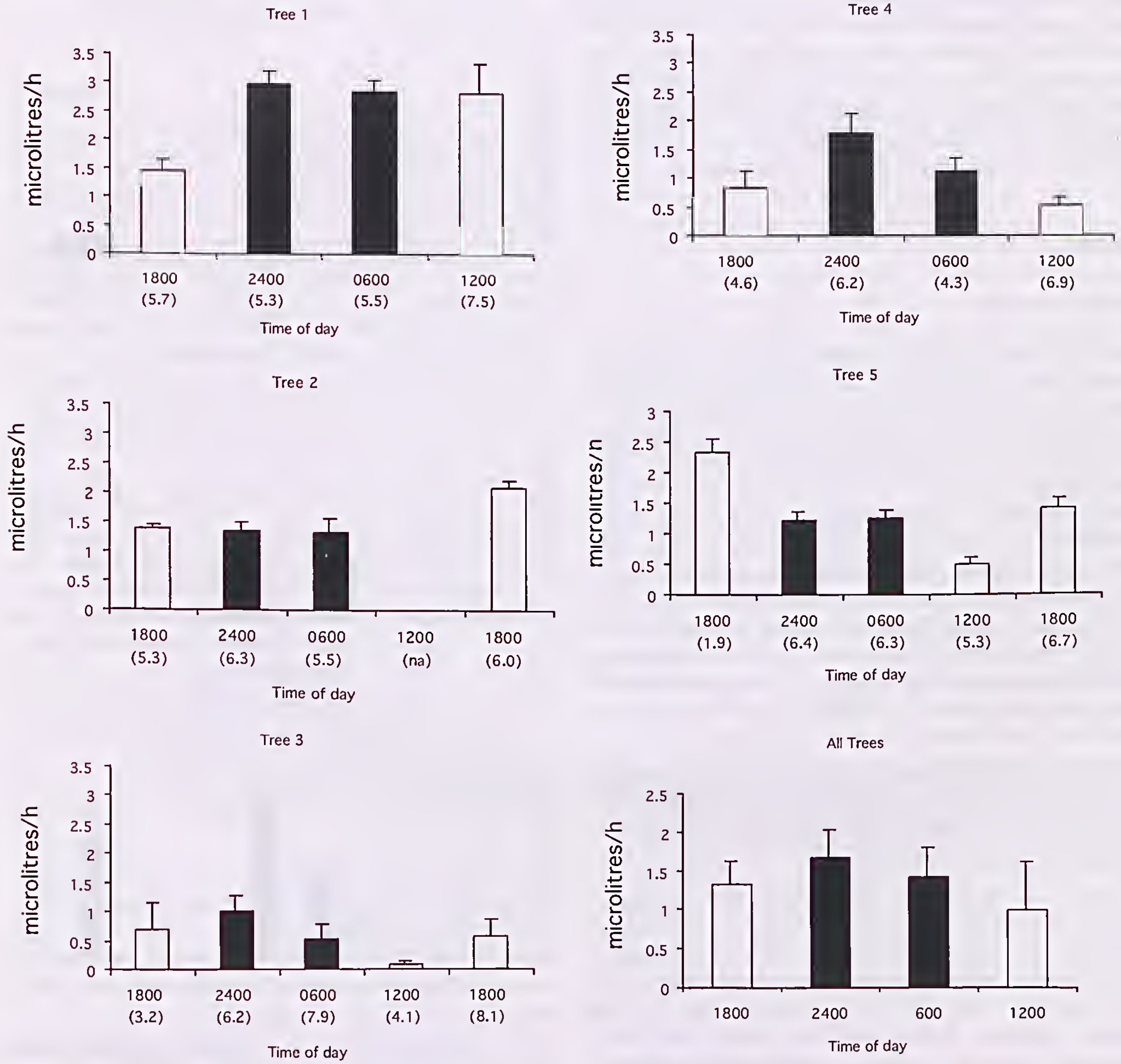

Fig. 1. Nectar secretion per flower (mean ± se; n = 6–10 per tree) at 6-h intervals in five *Corymbia gummifera* trees. Black bars are nocturnal periods, white bars are diurnal periods. The actual time (h) intervals between samples are shown is brackets below times of day. na = data not available.

could be expressed as the volume of nectar produced in the intervening interval. This assumes that rates of secretion are consistent within an interval and that if intervals are unequal it has not biased the comparison. Data were not available for Tree 2 at 1200 h because the exclusion bag had become dislodged. These flowers were emptied at this time and re-sampled at 1800 h. The flowers of Trees 3 and 5 were also resampled in this interval to allow a basic comparison of the two 1800 h intervals.

The sugar concentration of the nectar was determined from the above samples using a Brix temperature-compensated hand refractometer. The range in temperature during sampling in the second year was 14–22°C. Standing crop of nectar was also measured in the four trees sampled in the second year. This occurred at various times including after when the nectar secretion measurements were taken. A random sample of 10 flowers was removed from the tree to facilitate the measurement. Flowers were removed from branches away from those containing the bagged flowers. The constraints of positioning the cherrypicker precluded being able to disperse these flowers more broadly through a tree's canopy.

Results

Nectar secretion

Nectar secretion was highly variable among the five trees, ranging from 0.1 µl/h in Tree 3, to 3.0 µl/h in Tree 1. There was no consistent pattern among trees with regard to higher secretion in day or night samples (Fig. 1). Repeated measures analysis of variance of the diel cycle from 1800 h to 1200 h revealed that there were significant differences among the sample periods for three of the five trees (Tree 1: $F_{3,24}$=6.27, P=0.003; Tree 4: $F_{3,27}$=7.13, P=0.001; Tree 5: $F_{3,27}$=25.8, P=0.001). However, only Tree 4 showed a pattern of higher secretion in both nocturnal samples compared to diurnal samples. Each of the four other trees had a single diurnal period with equivalent or higher nectar secretion to those in the nocturnal period. For three of the trees, measurements were also recorded in a second 1800 h interval. This confirmed the variation in the rates of secretion.

The individual tree secretion data were averaged across all 5 trees to provide insight into any consistent pattern across the five trees (Fig. 1). This suggests that there is a trend for lower secretion in the 6-h period to 1200 h.

Nectar sugar concentration varied among trees and sample periods. Values were arcsine-square root transformed for analysis. For Tree 1, there was a significant difference (P=0.001) in concentration among the time periods. At 1800 h, it averaged 21.1% while it ranged from 11.4% to 15.3% for the other three time periods. For Tree 2, there was a significant difference (P=0.001) in concentration among the time periods, but the range in mean values was quite low (7.1–9.9%). For Tree 3, concentrations varied from 8–13%

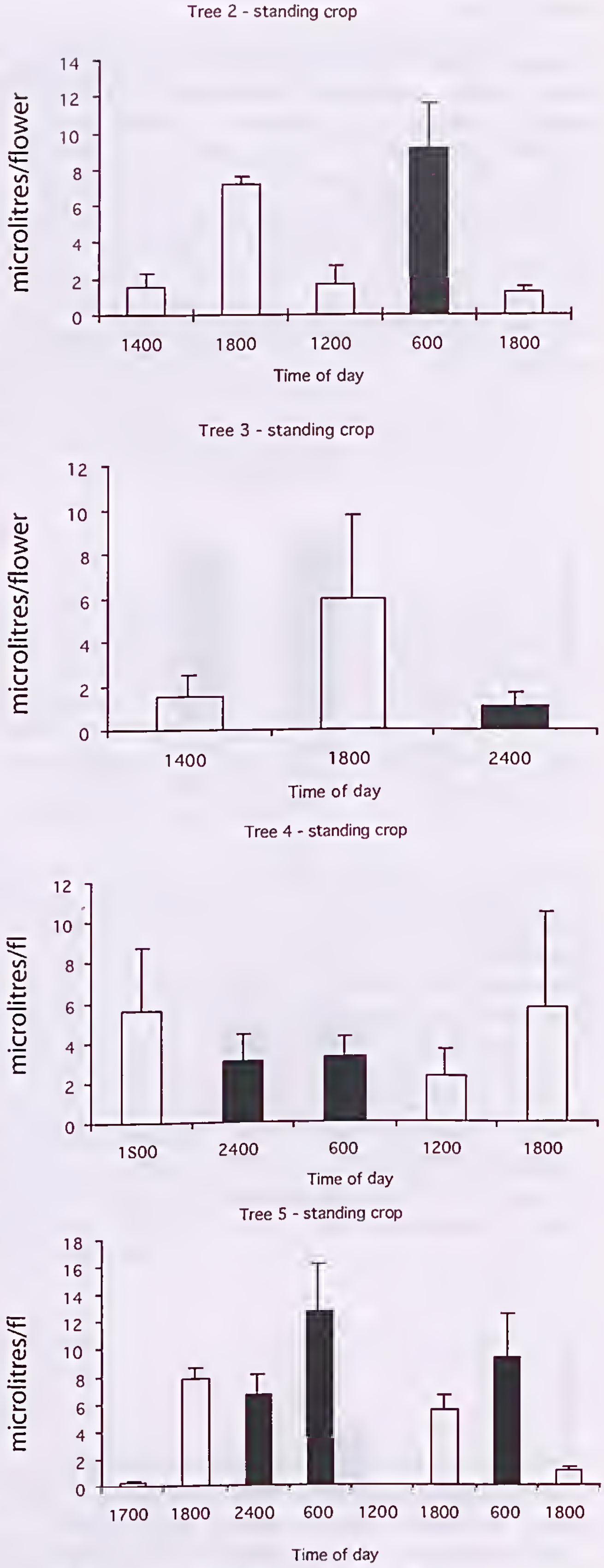

Fig. 2. Standing crop of nectar (mean ± se) measured in four *Corymbia gummifera* at different times. Different flowers (n=10) were measured in each time period. Black bars are nocturnal periods, white bars are diurnal period.

but the low volumes of nectar in many samples precluded determining the concentration and therefore analysis could not be conducted. There was no significant difference among sample periods for Tree 4 (7.5–17.5%) or Tree 5 (6–10%). Nectar concentration averaged 9.3 % overall for Trees 2–5 that were measured in the second year. There appeared to be little relationship between nectar volume and sugar concentration.

Nectar standing crop

Nectar standing crops varied greatly among the trees (Fig. 2). Standing crops varied from about 1 µl in Tree 3 to 12.6 µl in Tree 5. High standing crops of about 5 µl or higher were observed during the day in all trees while crops of that size were observed at night in Trees 2 and 5.

Discussion

Although only a small number of trees was sampled in this study, the variability in nectar secretion was such that there appears to be little temporal pattern to it, though there may be a trend of slightly lower secretion in the period 0600–1200 h. Flowers produced nectar at approximately 0.5–3 µl per hour throughout the diel cycle. Pyke (1985) described daily nectar production of 12.9 ± 1.5 µl per flower in *Corymbia gummifera* near Sydney. This value actually represents the dawn standing crop (assuming there were no nocturnal nectarivores). This is within the range of measurements in this study for a 12-h night. Standing crops at different times of the day or night were variable but often > 6 µl per flower.

Few studies have measured nectar secretion in eucalypts. Horskins and Turner (1999) found that 90% of the daily production of nectar by *Eucalyptus costata* occurred overnight. They reported secretion of about 0.6 µl per hour overnight compared to about 0.02–0.17 µl per hour during the day. This was largely consistent with an earlier assessment of the same species (referred to as *E. incrassata*) by Bond and Brown (1979), though these authors reported an average of only 0.11 µl of nectar per hour overnight. McCoy (1990) has also documented greater levels of nectar production at night in *Eucalyptus porrecta* and *Eucalyptus confertiflora* in northern Australia. These findings contrast with the present study that showed reasonably consistent secretion during the day and night.

The complete array of floral visitors to *Corymbia gummifera* was not documented in this study. However, detailed nocturnal research at the site revealed that three species of gliding possums (*Petaurus australis, Petaurus breviceps, Acrobates pygmaeus*) were abundant and regularly visited blossoms of *Corymbia gummifera* and other eucalypts. Indeed, eucalypt-nectar feeding accounted for 70% of feeding observations on *Petaurus australis* (Goldingay 1990). Nocturnal insects also visited flowering *Corymbia gummifera* though they were not quantified, while grey-headed flying foxes (*Pteropus poliocephalus*) were abundant and fed in flowering *Corymbia gummifera* when flowering trees were abundant (Goldingay 1990). Diurnal insects, honeyeaters and lorikeets were present in large numbers and fed in the blossoms of *Corymbia gummifera* during the day. The relative contribution of these different floral visitors to pollination in *Corymbia gummifera* is unknown but the abundance of such an array of visitors is suggestive of a generalised pollination system. This is likely to prove a rich area of research in future years because the advent of new genetic techniques may allow resolution of contributions to gene flow from different pollinator groups, possibly simply by sampling pollen that they carry. However, the fitness consequences of pollen transferred over different spatial scales would remain unknown.

It is very common among plant species to be visited and pollinated by more than a single species of animal. Indeed, plant species are commonly visited by diverse types of pollinators (e.g. bats & hummingbirds, Sahley 1996; lizards, flies & wasps, Travest & Sáez 1997; moths & bees, Groman & Pellmyr 1999; bees & flies, Kephart et al. 1999; bats, birds & non-flying mammals, Tschapka & von Helversen 1999; moths and bats, Arizaga et al. 2000). Most studies are unable to identify whether all floral visitors pollinate equally or whether some may be more effective than others, though some attempt is usually made by authors to highlight the species they considered most important, based on visitor observation. Relatively few studies have assessed the contribution to seed production made by different pollinators for plants with mixed pollinator guilds (e.g. Goldingay et al. 1991; Groman & Pellmyr 1999; Hingston et al. 2004).

There has been some speculation that flying-foxes and birds may be more significant pollinators of eucalypts than other floral visitors because they have the potential to carry pollen over long distances (see McCoy 1990; Eby 1991; House 1997; Palmer & Woinarski 1999). Although eucalypts show higher seed set from cross compared to self pollination (Potts & Wiltshire 1997), it is yet to be established that highly mobile floral visitors transfer high loads of interpopulation pollen or that this is beneficial to the plants. It is worth noting that wider-ranging flying pollinators may deliver pollen that leads to out-breeding depression, due either to a disruption of local adaptation or to genetic incompatibilities (e.g. Waser & Price 1994). Moreover, flying pollinators may be more likely to carry mixed pollen loads from different species that reduce pollination success. This is clearly an area where many hypotheses can be generated regarding the effectiveness of various pollinator groups. Such research is needed if we desire to adequately manage and conserve our eucalypt-dominated ecosystems that continue to be fragmented and in which significant pollinators may be declining in abundance.

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